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Waste Heat Recovery Potential in Selected Industries

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WASTE HEAT RECOVERY POTENTIAL IN SELECTED INDUSTRIES

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The Energy Pollution Control Division of the IERL-Ci is currently conducting a program intended to assess the relative economic/environmental impacts of waste heat utilization. The reasons for EPA involvement are twofold.

- Increasing the efficiency of energy utilization may be considered a pollution control alternative in that the resulting decrease in fuel consumption will also result in a corresponding decrease in quantity of pollutants discharged.
- It is necessary to insure that as waste heat recovery technologies and more efficient systems are developed, new pollutants are not generated which would adversely affect the environment.

The objective of this study was to identify the points, qualities, and quantities, of waste heat discharged to the environment by energy intensive industries and emerging technologies for energy development. These data may then be utilized to evaluate various heat management alternatives and to further define and identify potential beneficial uses of these discharges.

Further information on this subject may be obtained from the Energy Pollution Control Division of the Industrial Environmental Research Laboratory, of the United States Environmental Protection Agency, Cincinnati, Ohio, 45268.

David G. Stephan
Director
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ABSTRACT

This research project was initiated with the overall objective of identifying the points, qualities, and quantities, of waste heat discharged to the environment by energy intensive industries and emerging technologies for energy development. These data may then be utilized to evaluate various heat management alternatives and to further define and identify potential beneficial uses of these discharges.

The first task performed during the course of this study consisted of identifying industries and emerging technologies which offered the greatest potential for discharging substantial quantities of waste heat to the environment. For each of these industries, a study was conducted to document the points, qualities, and quantities of all waste heat discharges to the environment. The major source of data collected on flue gases was the National Emissions Data System's (NEDS) Point Source Listings. These data were then verified according to point sources of discharge by discussion with various industry officials and by correlation with other related studies conducted both by the Environmental Protection Agency (EPA) and The Department of Energy (DOE). Data on wastewater and on-contact cooling waters containing significant quantities of waste heat were also identified, when possible, utilizing EPA Development Documents for Effluent Limitations, correspondence with Industrial Pollution Control Officers, literature surveys, and various United States Government-sponsored Research and Development reports.

This report also includes a discussion of the various waste heat recovery technologies currently available for the recovery of waste heat energy as well as a brief discussion of the various environmental impacts associated with the discharge of waste heat to the environment.

This report concludes that several energy intensive industries discharge in excess of 50% of their purchased fuel and electric energy as waste heat. The Flat Glass Industry discharges 75% of its purchased fuels and electricity as waste, while Paperboard Mills, Cyclic Crudes and Intermediates, and Nitrogenous Fertilizers discharge less than 10% of their purchased fuels and electricity.

The waste heat discharges of these industries is also differentiated according to the potential to recover this waste heat energy. Waste heat energy contained in flue gas discharges at temperatures greater than 350°F were termed Btu Available. The report concluded that only three industries: Flat Glass, Petroleum Refining, and Glass Containers, discharge more than 50% of their waste heat energy at temperatures greater than 350°F. This indicates that the majority of waste heat energy discharged by Energy Intensive Industries is discharged as low grade waste heat (i.e. less than 350°F).

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LIST OF ABBREVIATIONS

ABBREVIATIONS

EPA -- United States Environmental Protection Agency

NEDS -- National Emissions Data System

DOE -- Department of Energy

SIC -- Standard Industrial Classification

NEC -- Not Elsewhere Classified

bbl -- barrel

Btu -- British thermal unit

BPD -- Barrels per day

gpm -- gallons per minute

Kwh -- Kilowatt hour

BDT -- Bone Dry Ton

CONVERSION TABLE

(SI units)

This publication uses customary English units in order to remain consistent with the units reported in the data upon which this report was based. The reader interested in conversion to the International System of Units (SI) may utilize the following table for those units contained in this report.

Quantity	To convert from	To	Multiply By
Length	foot	m	3.048×10^{-1}
Area	sq ft	m^2	9.290×10^{-2}
Volume	cu ft	m^3	2.832×10^{-2}
	gallon	m^3	3.785×10^{-3}
Temperature	°F	°C	$t_c=(t_f-32)/1.8$
Mass	pound	kg	4.536×10^{-1}
Pressure	psi	Pa	6.895×10^{3}
Energy	Btu	J	1.055×10^{3}
	Kwh	J	3.600×10^{6}
Flow	gpm	m^3/s	6.309×10^{-5}
	cfm	m^3/s	4.719×10^{-4}
Barrel (Petroleum)	42 gal	m^3	1.590×10^{-1}

SECTION 1

INTRODUCTION AND SUMMARY

INTRODUCTION

The United States purchased approximately 73 quadrillion Btu (quads) of fuels and electricity in 1977 with slightly over 24.1 quads, including inefficiencies associated with electricity generation, being purchased by the industrial sector alone. Approximately 6.5% of the Nation's purchased energy in 1977 was discharged as waste heat to the environment by the eight most energy intensive industries. Approximately four percent was discharged as flue gases, and two percent was discharged as identified waste water and cooling water discharges.

Of the industrial sector's purchased fuels and electricity, approximately 37% was discharged to the environment as waste heat by major energy intensive industries included in this study. Flue gases accounted for about 23%, and identified wastewaters and cooling waters accounted for about 14%.

This wasted heat is not only costly for industry and hence the consumer, but it is becoming increasingly apparent that thermal pollution affects climatic and biotic conditions. In light of the present energy shortage and environmental problems faced today, it is apparent that waste heat should be minimized through process design and/or recovery techniques.

BACKGROUND

The Energy Pollution Control Division of the U.S. Environmental Protection Agency's (EPA) Industrial Environmental Research Laboratory has been conducting a program intended to assess the relative economic/environmental impacts of waste heat utilization. The reasons for EPA involvement are twofold:

- o Increasing the efficiency of energy utilization may be considered a pollution control alternative in that the resulting decrease in fuel consumption will also result in a corresponding decrease in quantity of pollutants discharged.
- o It is necessary to insure that as waste heat recovery technologies and more efficient systems are developed, new pollutants are not generated which would adversely affect the environment.

OBJECTIVE

The objective of this study was to identify the points, qualities, and quantities, of waste heat discharged to the environment by energy intensive industries and emerging technologies for energy development. These data may then be utilized to evaluate various heat management alternatives and to further define and identify potential beneficial uses of these discharges.

PROCEDURE

The first task performed during the course of this study consisted of identifying industries and emerging technologies which offered the greatest potential for discharging substantial quantities of waste heat to the environment. For each of these industries, a study was conducted to document the points, qualities, and quantities of all waste heat discharges to the environment. The major source of data collected on flue gases was the National Emissions Data System's (NEDS) Point Source Listings as reported by July, 1977. These data were then verified according to point sources of discharge by discussion with various industry officials and by correlation with other related studies conducted both by the EPA and The Department of Energy (DOE). Data on wastewater and non-contact cooling waters containing significant quantities of waste heat were also identified, when possible, utilizing EPA Development Documents for Effluent Limitations, correspondence with Industrial Pollution Control Officers, literature surveys, and various United States Government-sponsored Research and Development.

The scope of work performed during this study is summarized briefly as follows:

- Define energy intensive industries and emerging technologies and identify existing industries which may be defined as energy intensive.
- Select those industries thought to discharge the greatest portion of waste heat to the environment.
- Review, document, and analyze the process details of selected industries and emerging technologies to determine the need and means for further subcategorization of the industrial groups.
- Conduct in-depth literature and permit surveys to establish base data on the nature and quantity of these thermal discharges.
- Obtain specific data not available elsewhere through correspondence with the various industries.
- Review, document, and analyze all data obtained and prepare charts, tables, etc. indicating the points, quality and quantity of thermal discharges.

SUMMARY

Selection of Industries

The energy intensive industries selected for this report were chosen on the premise that those industries that consumed the greatest quantities of energy offered the greatest potential for discharging substantial quantities of waste heat to the environment. Consideration was also given to the thermal intensity and diversification of each industry. Table 1 lists those 4-digit Standard Industrial Classifications (SIC) included in the study.

TABLE 1. STANDARD INDUSTRIAL CLASSIFICATIONS

SIC#	CLASSIFICATION	SIC#	CLASSIFICATION
2611	Pulp Mills	3211	Flat Glass
2621	Paper Mills (except Building Paper)	3221	Glass Containers
2631	Paperboard Mills	3229	Pressed and Blown Glass
2812	Alkalies and Chlorines	3241	Cement Hydraulic
2813	Industrial Gases	3274	Lime
2819	Industrial Inorganic Chemicals	3312	Blast Furnace and Steel Mills
2865	Cyclic Crudes & Intermediates	3321	Grey Iron Foundries
2869	Industrial Organic Chemicals	3331	Primary Copper
2873	Nitrogenous Fertilizers	3334	Primary Aluminum
2911	Petroleum Refineries		

Energy Intensive Industries

Since considerable variations exist in both the type and accuracy of data on wastewaters discharges between various SIC classifications, a comparison of the waste heat discharges from these classifications is limited to flue gases discharges only. Additional data on these waste heat discharges from wastewaters are contained in those sections of this report dealing specifically with each SIC.

Figure 1 presents the annual waste heat discharged by flue gases for the major energy intensive industries in 1977. Petroleum Refining, SIC 2911, discharged the largest quantity of flue gas waste heat to the environment. Steel Mills, SIC 3312, was the second largest annual discharger of flue gas waste heat. These two together represent approximately 50% of the total annual flue gas waste heat discharged by the nineteen SIC groups included in this study.

Figure 2 presents the percentage of the annual waste heat discharged by flue gases at temperatures above 350°F (177°C). The heat content of the waste heat discharges above 350°F (177°C), were considered "Btu Available" due to their greater potential for energy recovery via conventional "heat exchanger" devices.

Figure 3 presents the percent of purchased fuels and electricity discharged as flue gas waste heat by each SIC. This figure indicates that Flat Glass, SIC 3211, discharged more than 75% of the energy content of its purchased fuels and electricity as flue gas waste heat. Six industries, Flat Glass, Petroleum Refining, Hydraulic Cement, Blast Furnaces and Steel Mills, Primary Copper, and Lime, all discharged more than 50% of their purchased fuels and electricity as flue gas waste heat. Only three industries, Paperboard Mills, Cyclic Crudes and Intermediates, and Nitrogenous Fertilizers, discharged less than 10% of their purchased fuels and electrical energy as flue gas waste heat.

This figure also indicates that the Flat Glass Industry, SIC 3211, has the greatest percent of its flue gas waste heat discharged at temperatures greater than 350°F (177°C). Only three industries, Flat Glass SIC 3211, Petroleum Refining SIC 2911, and Glass Containers SIC 3221, discharge more than one half of their flue gas waste heat at temperatures greater than 350°F (177°C). The Paper and Allied Products (i.e., SIC 2611, 2621, 2631) discharged greater than 80% of their waste heat as low grade waste heat, at temperatures less than 350°F (177°C).

The percentages presented in Figure 3 may be considered somewhat conservative since the figures used in this analysis do not include wastewater and cooling water discharges nor do they account for the relative feedstock energy content. These figures are discussed in the individual industry evaluations contained in the complete report.

Figure 4 presents the annual flue gas waste heat discharged in the 10 EPA Regions. This indicates that EPA Regions 3, 5, and 6 (identified in Figure 5) have the greatest quantities of flue gas waste heat discharged to the environment. Region 5 has the greatest quantity of flue gas waste heat discharged. This waste heat is discharged primarily by the Steel, Petroleum, and the Organic Chemicals Industries.

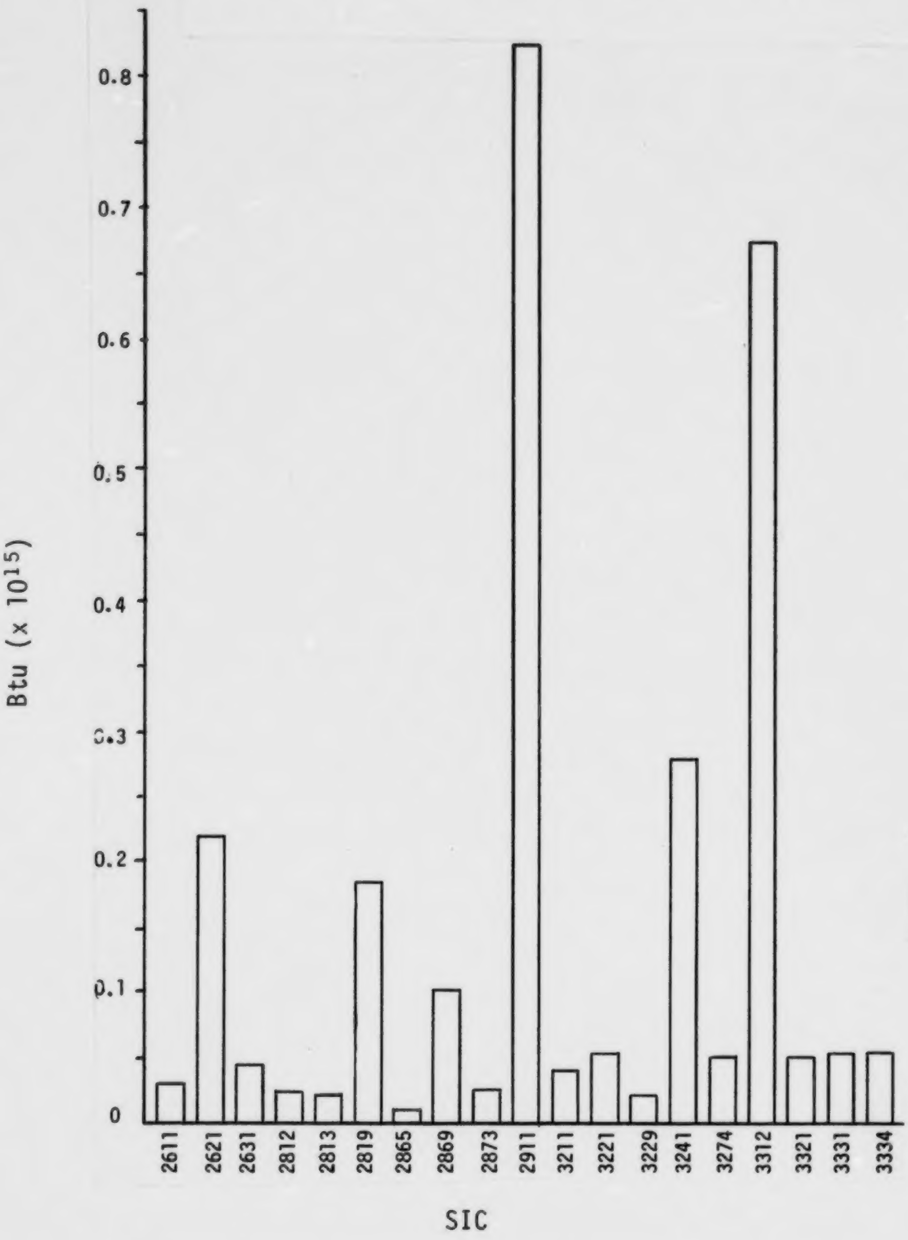


Figure 1. Annual waste heat discharged (flue gases only) by SIC numbers. (1977).

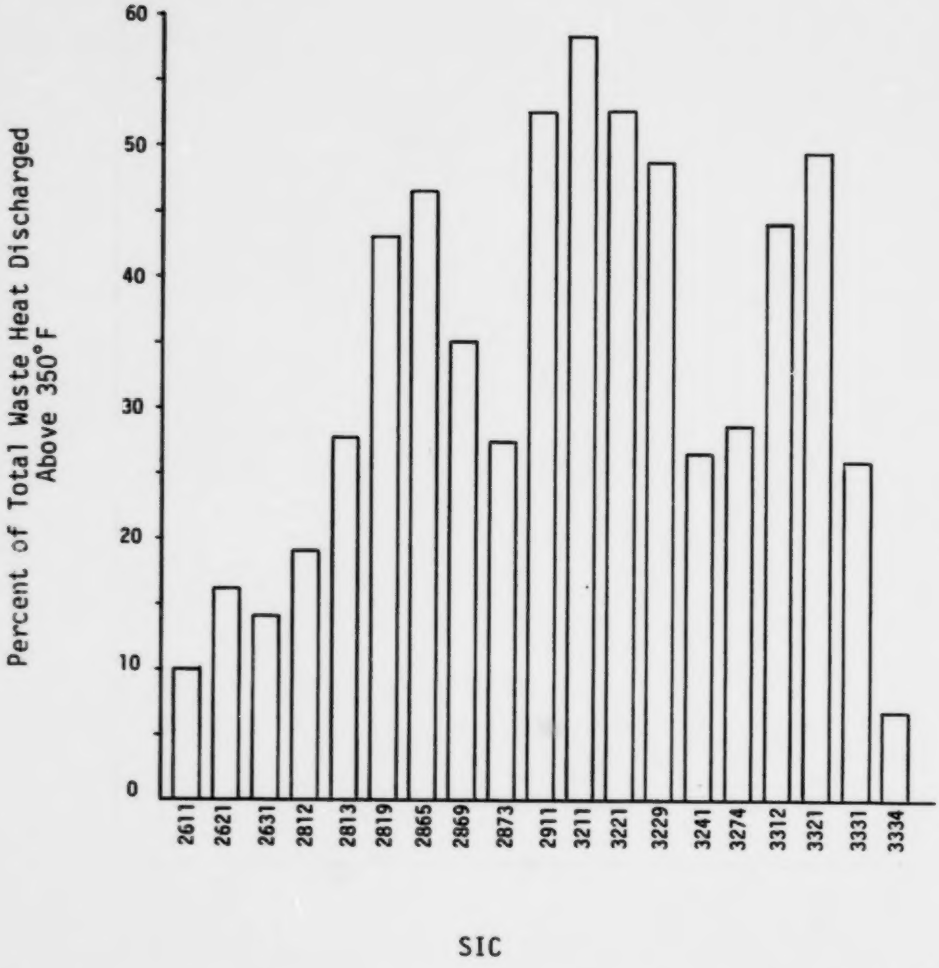


Figure 2. Percent waste heat discharged (flue gases only) above 350°F, by SIC number.

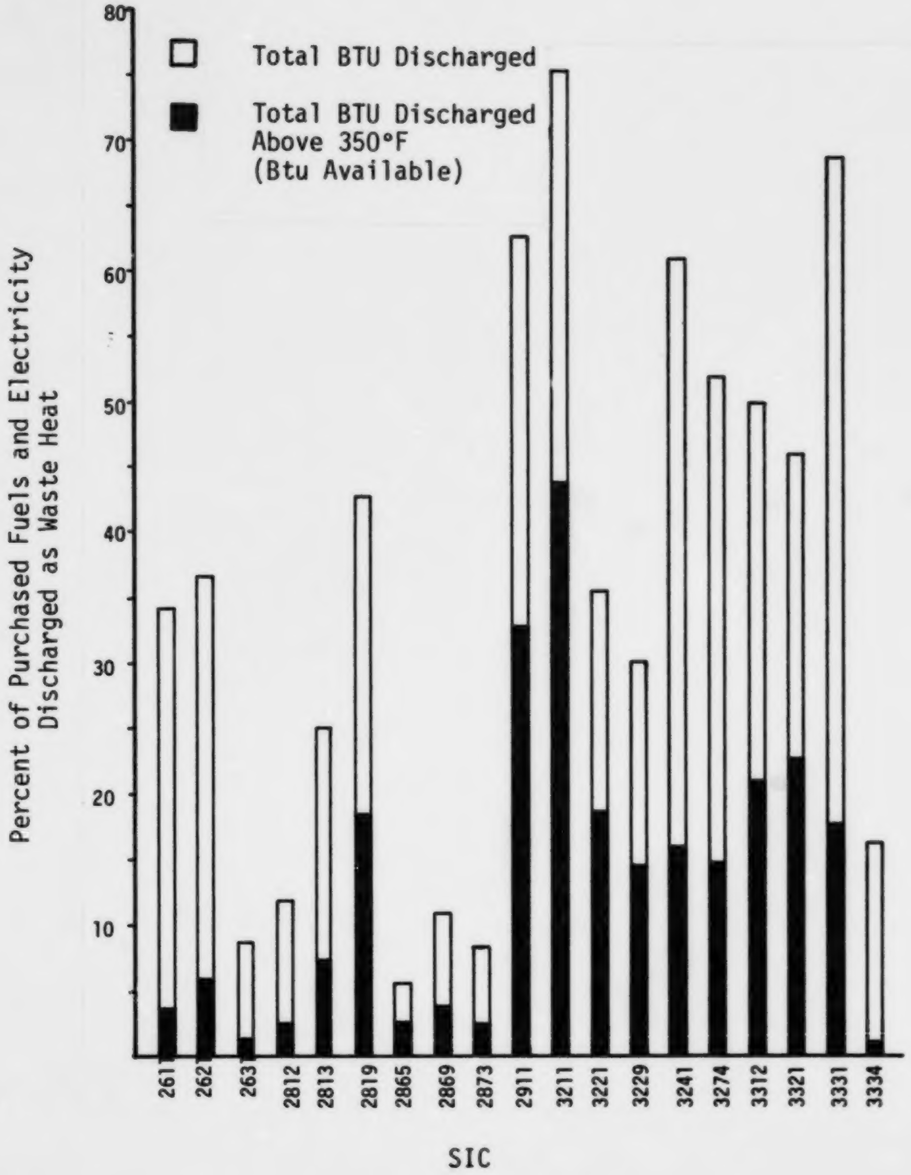
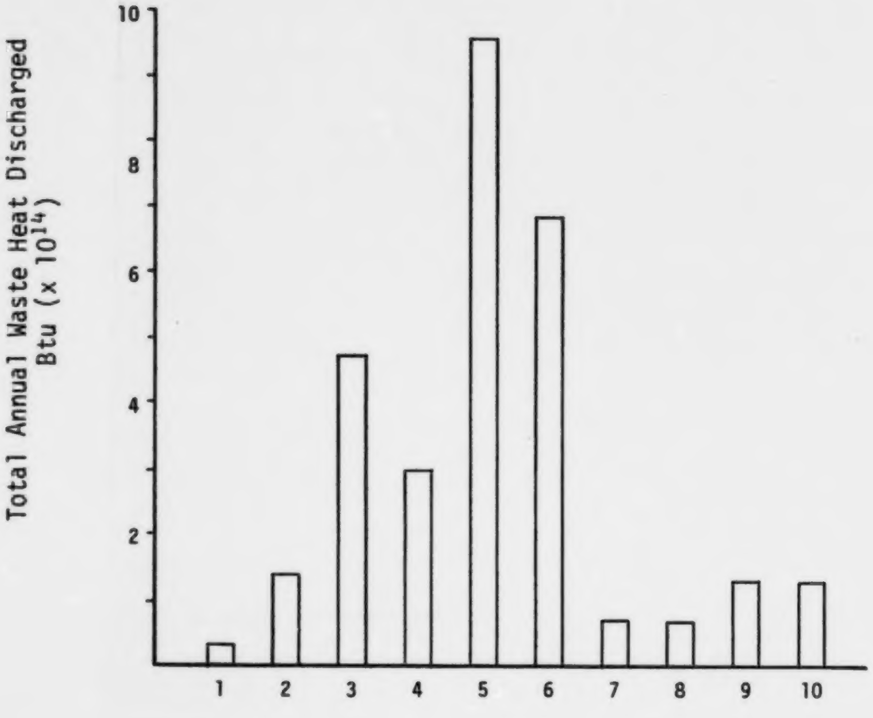


Figure 3. Percent of purchased fuels and electricity discharged as waste heat by SIC number (1977).



Regions

Figure 4. Annual waste heat discharged (flue gases only) by EPA region (1977).

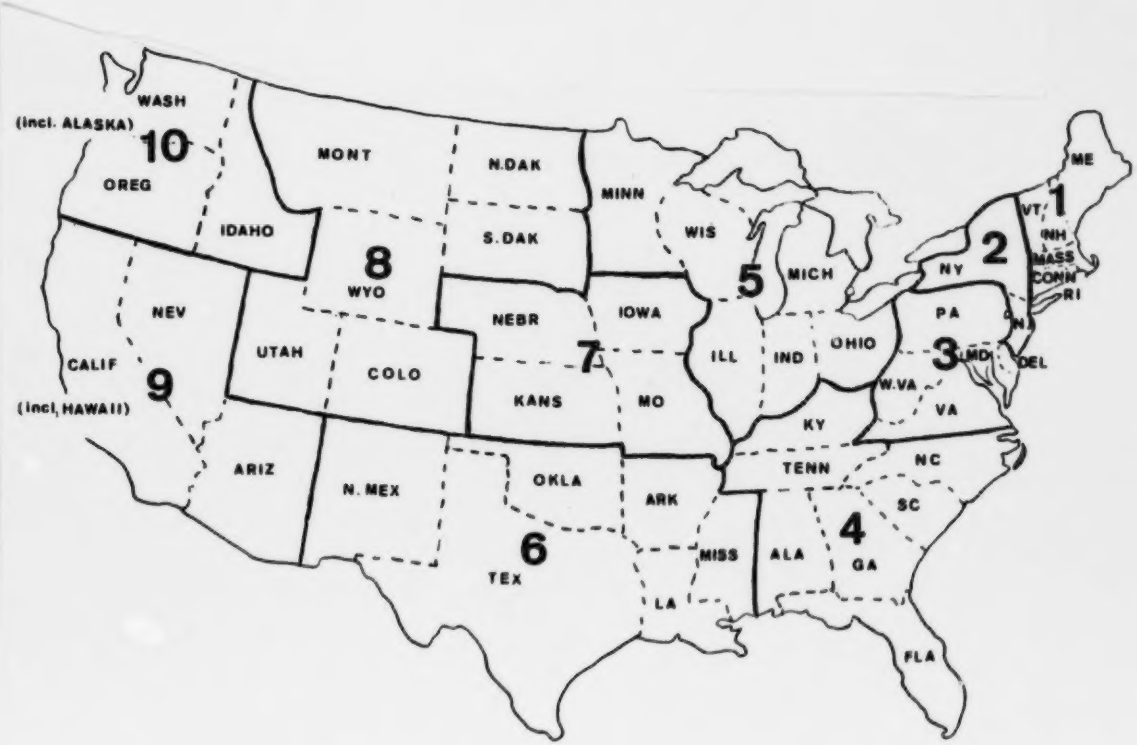

WASH
(incl. ALASKA)
10
OREG
IDAHO
MONT
N.DAK
S.DAK
MINN
WIS
MICH
5
8
WYO
NEBR
IOWA
7
ILL
IND
OHIO
NEV
CALIF
9
(incl. HAWAII)
UTAH
COLO
KANS
MO
KY
ARIZ
N. MEX
OKLA
6
TEX
ARK
MISS
LA
TENN
ALA
4
GA
SC
NC
FLA
1
ME
VT
NH
MASS
CONN
RI
2
NY
NJ
PA
3
MD
DEL
W.VA
VA

Figure 5. EPA regions.

Region 6's waste heat discharges were due primarily to waste heat discharged by Petroleum, Organic Chemicals, Cement, Inorganic Chemicals and Papermills. The waste heat discharged in Region 3 were discharged primarily by the Industrial Gases, Steelmills, Petroleum Refineries, and Cement Industries.

These data reflect the regional potentials for commercial use of low-grade waste heat in the fields of space heating, soil warming, agriculture, and other applications.

Emerging Technologies

The emerging technologies for energy development selected for this study are coal conversion processes, oil shale development, and uranium enrichment. Considerable difficulty was experienced in obtaining reliable waste heat data on emerging technologies since pilot plants constructed thus far were intended to demonstrate process feasibility rather than optimizing energy efficiencies. Consequently, data from these pilot plants did not necessarily represent waste heat discharges that would result from full-scale commercial operation of these plants.

The coal conversion processes currently undergoing development range in overall energy conversion efficiencies from a low of 38% for the Fisher-Tropsh coal liquefaction process to a high of 80% for the low BTU gas synthesis process. This overall efficiency is defined as the heating value of the refined fuel products divided by the heating value of the coal feedstock. The result indicates that a large percentage of the heating value of the feedstock is rejected into the environment. If energy-self sufficiency is to be realized, it could be assumed that imported fuels would be replaced by domestic fuels converted from coal. During 1976, the United States imported 1900 million barrels (bbl) of crude oil, a figure that represents over 40% of the domestic fuel consumption. Assuming a crude oil of 5.8 x 10^6Btu/bbl and a nominal fuel conversion efficiency of 67% for coal conversion processes, the heat rejected from fuel conversion plants producing the same quantity of fuel as was imported, would equal 3.02 x 10^{13}Btu/day, or 1.10 x 10^{16}Btu/year.

Prior to the completion of this study, the TOSCO II Retort was the oil shale retorting process considered most promising on the basis of ease of environmental effluent control, shale oil extraction efficiency, and technical advancement. Although data were not available to evaluate accurately the thermal efficiency of this and other viable processes, two major sources of waste heat discharges were identified. The first is the evaporation of cooling water. A 50,000-bbl/day TOSCO plant, operating on 35 gallon per ton oil shale, resulted in the evaporative losses from the cooling towers of 1000 gallons per minute. This corresponds to a thermal discharge of approximately 240 million Btu per 1000 bbl of upgraded shale oil.

The other major source of waste heat from oil shale processing stems from the heat content of the spent shale. The TOSCO process produces approximately 2.14 x 10^6 lb of spent shale per 1000 bbl of upgraded shale oil produced, corresponding to 64.35 x 10^6Btu of waste heat per 1000 bbl produced.

Note, however, that those processes utilizing in-situ methods of oil recovery will not generate this hot spent shale and the subequent problems of disposal.

The three gaseous diffusion uranium enrichment plants currently operating in the United States release approximately 1.71×10^{14}Btu per year of waste heat. This waste heat is discharged via noncontact cooling waters.

Waste Heat Recovery Technology

Several waste heat recovery technologies were reviewed to identify their potential for recovering waste heat energy from a fluid (i.e., liquid or gaseous waste stream, product, or byporduct, and returning it to a process stream in such a manner that a net heat energy transfer resulted in a credit to the overall energy balance of the process. These processes and devices are summarized below as a function of their optimum operating temperature ranges.

High Temperature Range, 1200°F (649°C) to 2000°F (1093°C):

- Radiation recuperator
- Convection recuperator
- Ceramic heat wheels
- Refractory regenerators

Medium Temperature Range, 250°F (121°C) to 1200°F (649°C):

- Metallic heat wheel
- Passive gas to gas regenerator (air preheater)
- Heat pipe exchanger
- Finned tube heat exchanger (economizers)
- Shell and tube heat exchangers
- Waste heat boilers
- Gas and vapor expanders
- Organic rankine cycle heat engine

Low Temperature Range, subzero to 250°F (121°C):

- Heat pumps

Environmental Impacts of Waste Heat

The environmental impacts which may result from the discharge of waste heat to the environment may be separated into two general categories:

1) those impacts resulting from the release to the environment of the various pollutants contained in the waste heat stream, and 2) those impacts resulting from the release to the environment of the heat energy contained in the waste heat stream.

The environmental impacts resulting from the release of pollutants are specific to the composition and volume of each discharge. However, any action which results in an increase in the efficiency of energy utilization, (whether it is accomplished by waste heat recovery or general conservation practices) may be considered as a pollution control alternative in that these actions will result in a reduction in fuel consumption, with a corresponding decrease in the quantity of pollutants discharged.

The greatest potential impact of waste heat discharges is to natural bodies of water and their aquatic ecoystem. Although a large number of studies have been and are being conducted in attempts to further define these cause and effect relationships, considerable data is still lacking. Some of the known and reported effects associated with temperature increases of natural waterways are: decreasing gas (oxygen) solubilities; changes in species diversity, metabollic rates, reproductive cycles, digestive and respiration rates, behavior of the aquatic organisms; and increasing the parasitic bacterial populations. All of these have the potential of creating an unbalanced aquatic ecosystem.

Conclusions and Recommendations

Significant quantities of waste heat are discharged to the environment by energy intensive industries within the industrial sector. This discharged waste heat affects the well-being of our nation by:

- o Increasing our dependence on imported fuels;
- o Having an adverse environmental impact on air quality as a result of increased fossil fuel combustion for power generation (i.e., increased quantities of SO_2, NO_x, etc.);
- o Potentially altering local climatic conditions due to the release of significant quantities of heat into the atmosphere; and/or
- o Adversely impacting aquatic ecosystems which are used as heat sinks.

In order to minimize the adverse impacts of waste heat discharges, support should be continued for programs which foster energy conservation, either through the development of new, more efficient processes or through the use of efficient, low cost waste heat recovery devices. A variety of conventional waste recovery devices are currently available. However, there are two areas where the development and demonstration of new devices could significantly enhance the technology of waste heat recovery.

The first application is for the utilization of low grade waste heat for the direct conversion to electric energy through the use of various heat engine devices. The development of low-cost efficient heat pumps and Organic Rankine Cycle Heat engines are two devices which could foster increase waste heat recovery of low grade waste heat resources (i.e., less than 250°F (121°C)).

The second application is in the recovery of waste heat from high temperature flue gases. Current industrial waste heat recovery operators generally do not reduce flue gas temperatures much below 350°F (177°C) due to the potential condensation of corrosive liquids. Therefore, the development and demonstration of a waste heat recovery device which could reduce the flue gas temperature beyond the condensation temperature, while avoiding the high cost of corrosion resistant materials, would significantly enhance the incentives for more complete waste heat recovery.

The use of the NEDS-Point Source Forms offers a real potential for assisting investigations in identifying candidate waste heat recovery sources. However, there are several recommendations which could further enhance the usefulness of this data. These are discussed in more detail in Appendix A and are summarized as follows:

- More complete and specific NEDS Implementation Planning Program Process (IPP) codes for respondents to select from.
- A test loop should be included in the NEDS data to indicate obviously erroneous entries.
- Additional data should be requested which would indicate whether the waste heat discharges are continuous or intermittent.

Summary of Sections

This report organized into ten sections. Section 1 provides broad overview of the entire report. Section 2 describes the rationale used to select and evaluate the most energy-intensive industries in the U.S. Sections 3-7 define the individual SICs, including energy consumption, sources and qualities of waste heat, geographical distribution of the industry, and brief process descriptions. Section 8 describes several emerging technologies for alternate energy development which have a good potential to reduce the industrial sector's demand for conventional fuels. Section 9 presents the current and developmental methodologies used to recover waste heat. In conclusion, Section 10 relates the potential environmental impacts of waste heat discharges.

SECTION 2

DETERMINATION OF SELECTED INDUSTRIES

INTRODUCTION

The scope of work for this project consisted first of determining which industries offered the greatest potential for discharging significant quantities of waste heat to the environment, and secondarily, to consider the level of effort required to collect these data and their validity and usefulness. It was subsequently determined that this evaluation could be based upon four major parameters.

- o Total energy purchased by each 2-digit SIC classification
- o Total energy purchased by each 4-digit SIC classification
- o Industrial diversification
- o Thermal intensity factors

EVALUATION CRITERIA

Energy Purchased by 2-Digit Classifications

This evaluation was based on a ranking of the 2-digit standard industrial classifications (SIC) according to the total purchased energy consumed by each. This follows the logic that those 2-digit SIC categories that consumed the greatest quantities of energy may offer the greatest potential for discharging substantial quantities of waste heat to the environment. Figure 6 presents a distribution of industrial energy purchased by 2-digit SIC codes. From this figure it can readily be seen that a separation occurs between SIC 20 (Food and Kindred Products) and SIC 34 (Fabricated Metal Products).

The next task was to determine the percentage of the total industrial energy consumption represented by each 2-digit consumer. These data are presented in Table 2 which lists the thirteen (13) largest categories in decreasing order of total energy consumption. This figure presents the individual and cumulative percentages of the total industrial energy consumption represented by each of the 2-digit SIC categories. As indicated by these data, the first six categories account for 80% of the total industrial energy consumption. The inclusion of the seventh largest industrial consumer category only increases this figure by an additional 3 percent, thereby not justifying its consideration as a prime candidate (based on this evaluation method). Consequently, this evaluation indicated that only the top six 2-digit classifications should be considered. These were:

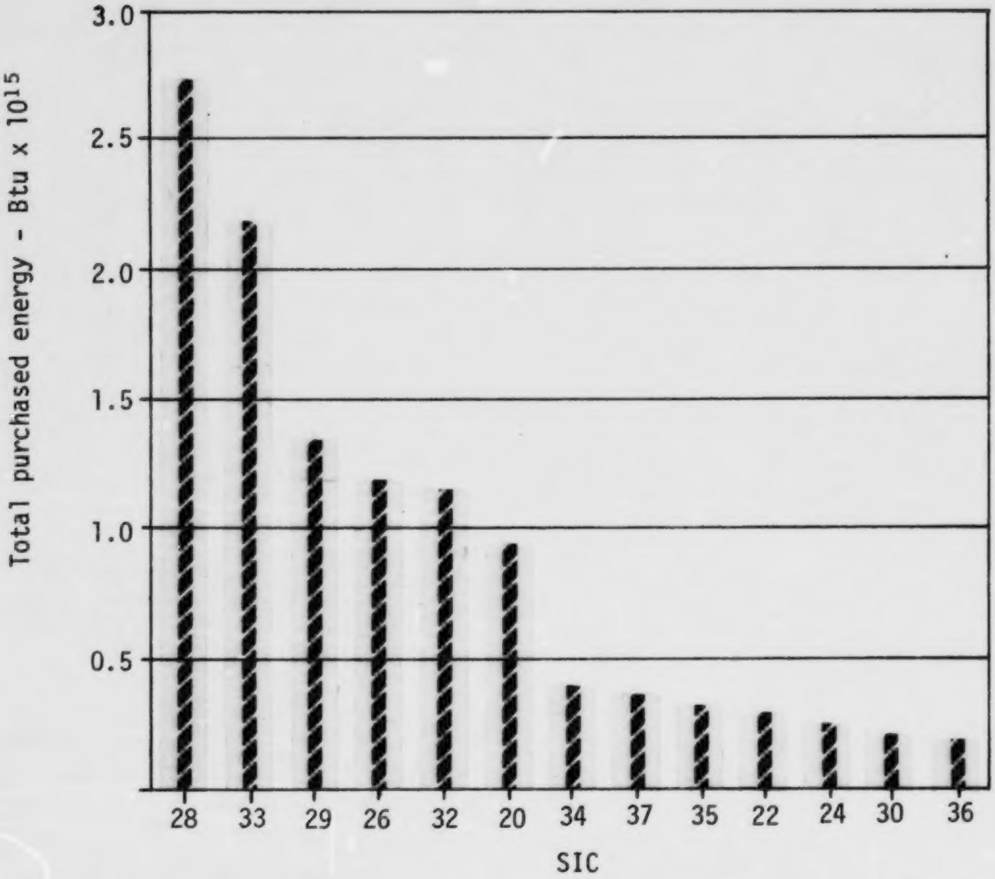


Figure 6. Total energy purchased by 2-digit Standard Industrial Classifications (1975).

Source: Annual Survey of Manufacturers - 1975
Fuels and Electricity Consumed.
Bureau of Census, Dept. of Commerce, Washington, D.C., 1976

TABLE 2. RANKING OF 2-DIGIT SIC CLASSIFICATIONS

SIC	Description	Fuel & Elec. Consumption Btu $x10^{15})^2$	% of Total Ind. Consumption[3] Individual	Cumulative
28	Chemicals & Allied Products	2.93	21.88	21.88
33	Primary Metal Industries	2.64	19.71	41.59
29	Petroleum & Coal Products	1.57	11.72	53.31
32	Stone, Clay, Glass Products	1.34	10.00	63.31
26	Paper & Allied Products	1.33	9.93	73.24
20	Food & Kindred Products	0.96	7.17	80.41
34	Fabricated Metal Products	0.41	3.06	83.47
37	Transportation Equipment	0.37	2.76	86.23
35	Machinery Except Electric	0.37	2.75	88.99
22	Textile Mill Products	0.32	2.39	91.38
24	Lumber & Wood Products	0.27	2.02	93.40
30	Rubber, Misc. Plastic Products	0.25	1.87	95.27
36	Electric, Electronic Equipment	0.25	1.87	97.14

[1] Source - Annual Survey of Manufacturers - 1974, Fuels & Electric Energy Consumed

[2] 3412 Btu per Kwh

[3] Total Industrial Consumption = 3924.7 x 10^9 Kwh (13.39 x 10^{15} Btu)

These were: SIC 28 - Chemicals & Allied Products
SIC 33 - Primary Metal Industries
SIC 29 - Petroleum and Coal Products
SIC 32 - Stone, Clay, Glass Products
SIC 26 - Paper & Allied Products
SIC 20 - Food & Kindred Products

Energy Consumption by 4-Digit SIC Classification

The second method used for the evaluation of candidate industries was based upon the ranking of 4-digit SIC classifications according to their purchased fuels and electric energy. For the purpose of this evaluation, a ranking of all 4-digit SIC classifications which purchased greater than 1×10^{10}Kwh (4.0×10^{13}Btu) was conducted and is presented in Table 3. This list became somewhat extensive, therefore making it necessary to limit this list to a reasonable number in compliance to the scope of work on this project. It was determined that selecting those 4-digit classifications whose fuel and electric consumption was greater than 8.0×10^{15}Btu (23.5×10^{9}Kwh) would yield a workable number of processes. A further review of these 19 categories indicated that they comprise only the top five 2-digit categories.

Industrial Diversification

This method of evaluation was developed in order to evaluate the number of different processes which would have to be investigated in depth in order to assure that all significant waste discharges were identified. This parameter was termed "Industrial Diversification" and was determined by the number of 4-digit SIC classifications within its respective 2-digit SIC classification. It is realized that this method is only a rough approximation since several differing process methods may be included within any single 4-digit classification. Each of which may have a significant effect on the quality and quantity of waste heat discharged to the environment. However, it was determined that for the majority of situations, this method of evaluating Industrial Diversifications would be adequate. These data become much more meaningful when it is reviewed with respect to the percentage of total energy consumed. Table 4 lists the major energy consuming 2-digit SIC classifications, and indicates the number of 4-digit SIC classifications which would have to be investigated in order to represent various percentages of its appropriate 2-digit classification.

As presented in Table 4, an investigation focused on the five largest 2-digit classifications, while accounting for 70% of the total energy consumed by each 2-digit category, would require an investigation of 17 separate 4-digit classifications. To include the next largest 2-digit SIC classification would almost double the total number of 4-digit SIC categories requiring investigation. Thus, fewer 4-digit SIC categories would have to be

TABLE 3. TOTAL ENERGY PURCHASED BY 4-DIGIT SIC[1]

4-DIGIT SIC	INDUSTRY GROUP AND INDUSTRY	PURCHASED FUELS AND ELECTRIC ENERGY (Btu x 10^{15})
3312	Blast Furnaces & Steel Mills	1.53
2911	Petroleum Refining	1.48
2869	Industrial Organic Chemicals	0.98
2621	Papermills, Except Building Paper	0.57
2631	Paperboard Mills	0.51
3241	Cement, Hydraulic	0.49
2819	Industrial Inorganic Chemicals	0.38
3334	Primary Aluminum	0.38
2873	Nitrogenous Fertilizers	0.25
2821	Plastic Materials and Resins	0.18
2812	Alkalies and Chlorine	0.18
2824	Organic Fibers, Non-Cellulosic	0.15
3221	Glass Containers	0.14
2865	Cyclic Crudes and Intermediates	0.14
3321	Gray Iron Foundries	0.12
3274	Lime	0.09
2822	Synthetic Rubber	0.09
2813	Industrial Gases	0.09
2611	Pulpmills	0.09
2063	Beet Sugar	0.08
2046	Wet Corn Milling	0.08
3331	Primary Copper	0.08
2011	Meatpacking Plants	0.08
3251	Brick and Structural Clay Tile	0.07
3229	Pressed and Blown Glass	0.07
2874	Phosphatic Fertilizers	0.07
3211	Flat Glass	0.06
3462	Iron and Steel Forgings	0.05
2082	Malt Beverages	0.05
2221	Weaving Mills, Manmade Fiber	0.05
2033	Canned Fruits and Vegetables	0.05
2051	Bread, Cake, Related Products	0.04
2026	Fluid Milk	0.04
2075	Soybean Oil Mills	0.04
2661	Building Paper and Board Mills	0.04
2262	Finishing Plants, Manmade Fiber	0.04
2062	Cane Sugar Refining	0.04

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[1] Source - Annual Survey of Manufacturers - 1974, Fuels and Electric Energy Consumed

TABLE 4. INDUSTRIAL DIVERSIFICATION

SIC #	DESCRIPTION	TOTAL #[1]	70%[2]	80%[2]	90%[2]
28	Chemicals and Allied Products	28	6	8	12
33	Primary Metals	26	2	5	10
29	Petroleum & Coal Products	5	1	1	1
32	Stone, Clay, Glass Products	27	6	9	13
26	Paper & Allied Products	17	2	2	4
20	Food & Kindred Products	47	16	21	28
34	Fabricated Metal Products	36	13	16	-
37	Transportation Equipment	17	4	5	-
35	Machinery, except Electrical	44	12	16	23
22	Textile Mill Products	30	8	11	15
24	Lumber & Wood Products	17	3	6	9
30	Rubber, Misc. Plastic Products	6	2	3	3
36	Electric, Electronic Equipment	39	15	20	27

[1] Total # of 4-Digit SIC Sub-categories within its respective 2-Digit SIC Classification.

[2] Number of largest 4-Digit SIC categories required to represent the appropriate percent of the Total Energy consumed by each 2-Digit SIC Classification.

investigated if it was intended to account for 80% of the largest five SIC classifications than would be necessary if only 70% of the largest six SIC classifications were to be considered. Therefore, this evaluation also indicated that this research effort should concentrate on the five largest 2-digit SIC classifications.

Thermal Intensity Factor

A major shortcoming of the previous three methods for evaluating candidate industries, is that these methods assume that the total waste heat discharged to the environment would be directly related to the total purchased fuels and electricity. This may not be the case for all industrial classifications. Some industries, which consume large quantities of electricity, may utilize this energy in other than thermal processes. Consequently, it was necessary to establish some ranking of the thermal intensity of particular industrial classifications.

Generally, if the energy required for an industrial process is thermal in nature, industry often finds the combustion of fossil fuels as the most economical method of producing this energy. In addition, certain industries, with large electrical and thermal requirements choose to produce their own on-site power. In both cases, the waste heat generated is related to the quantity of fossil fuel consumed. Therefore, it became apparent that a ratio of fossil fuel consumption to total energy consumption may serve as an indication of thermal intensity. This was the basis for the Thermal Intensity Factors presented in Table 5.

A shortcoming of this ranking is that Primary Metals, which rank as one of the largest energy consumers, does not rank among the six most thermally intensive industries. The reason for this is that Primary Aluminum, which consumes about 15% of the energy consumed by the Primary Metals Classification, has a thermal intensity factor of only 0.38. This stems from the fact that alumina is smelted to Aluminum in electrolytic cells which consume electric power and result in bath temperatures of 1600°F. This step in the processes contributes to the waste heat being discharged and should, therefore, be credited to fossil fuel in determining the thermal intensity factor for Primary Aluminum smelting, which (when credited to the fossil fuel consumed by the primary metals segment) yields a new thermal intensity factor of 0.87.

This ranking now indicates that the previously determined five largest 2-digit industrial classifications are also among the six most thermally intensive industries.

Final Selection

The previously discussed ranking methods were used as a guide in determining which major industrial segments would be investigated in this project in order to identify the major sources of waste heat, while representing a majority of the total energy consumed by the industrial sector.

Factors other than those previously discussed were also considered in

TABLE 5. THERMAL INTENSITY FACTORS

SIC #	DESCRIPTION	FACTOR[1]
29	Petroleum & Coal Products	.96
32	Stone, Clay, Glass Products	.93
26	Paper & Allied Products	.90
20	Food & Kindred Products	.87
28	Chemicals & Allied Products	.85
24	Lumber & Wood Products	.81
33	Primary Metals	.79
34	Fabricated Metal Products	.79
35	Machinery, Except Electrical	.75
37	Transportation Equipment	.74
30	Rubber, Misc. Plastic Products	.74
22	Textile Mill Products	.71

[1] Factor = Purchased Fuels (Kwh-equiv)/Total Purchased Fuel and Electricity (Kwh - equiv.)

the evaluation. In the final selection of specific 4-digit SIC classifications, some weight was also given to the nature and sources of other studies focusing on energy consumption and utilization, so that this report could be utilized with these previously published reports in developing a more detailed picture of the energy utilization by these industries. For this reason, some 4-digit SIC categories, which if considered independently may not have been included, were so in this case because the data upon which this report is based was not presented in a way which would allow the data on a specific 4-digit classification to be readily segregated.

Upon review of the factors previously described, it was decided that this research effort should concentrate on the five largest energy consuming industrial segments. Table 6 presents the 4-digit SIC categories which were included in this study, as well as the total fuel and electric energy consumed by each category. These 4-digit SIC categories account for 57.1% of the total fuel and electric energy consumed by the industrial sector in 1974.

TABLE 6. SELECTED INDUSTRIES BY 4-DIGIT SIC

2-DIGIT SIC	4-DIGIT SIC	PURCHASED FUEL AND ELECTRICITY (Kwh-Equiv) (10^9 Kwh)	PERCENT OF 2-DIGIT SIC
28	Chemicals, Allied Products	858.1	
	2812-Alkalies & Chlorine	53.0	6.2
	2813-Industrial Gases	25.6	3.0
	2819-Industrial Inorganic Chemicals	112.4	13.0
	2865-Cyclic Crudes & Intermediates	41.4	4.8
	2869-Industrial Organic Chemicals	288.6	33.6
	2873-Nitrogeneous Fertilizers	73.2	8.5
	4-Digit Total	594.2	69.2
33	Primary Metals	774.0	-
	3312-Blast Furnace & Steel Mills	448.4	58.0
	3321-Gray Iron Foundries	35.2	4.5
	3331-Primary Copper	22.9	2.9
	3333-Primary Aluminum	110.0	14.2
	4-Digit Total	616.5	79.6
29	Petroleum and Coal Products	459.4	-
	2911-Petroleum Refining	435.0	94.7
	4-Digit Total	435.0	94.7
32	Stone, Clay, Glass Products	391.5	-
	3211-Flat Glass	18.9	4.8
	3221-Glass Containers	41.2	10.5
	3229-Pressed & Blown Glass	20.8	5.3
	3241-Cement, Hydraulic	144.8	37.0
	3274-Lime	28.7	7.3
	4-Digit Total	254.4	65.0
26	Paper & Allied Products	390.0	-
	2611-Pulpmills	25.1	6.4
	2621-Papermills	167.8	43.0
	2631-Paperboard Mills	149.7	38.0
	4-Digit Total	342.6	87.8
	Sum 4-Digit Totals	2,242.7	
	Percent of Total Industrial Energy Consumed		57.1%

SECTION 3

PETROLEUM REFINING - SIC 2911

GENERAL DESCRIPTION

The petroleum refining industry, as defined by the Bureau of Census, are those establishments primarily engaged in producing gasoline, kerosene, distillate fuel oils, lubricants, and other products from crude petroleum and its fraction products, through straight distillation of crude oil, redistillation of unfurnished petroleum derivatives, cracking, or other processes. The petroleum refining industry is one of the most complex and technically sophisticated industries in the United States. There are about 250 United States refineries processing from 400,000 to a few hundred barrels per day (BPD) of crude petroleum. Total United States refining capacity, in 1974, was 14,486,000 BPD with 4.38×10^9 barrels processed.

GEOGRAPHICAL DISTRIBUTION

Within the U.S., refineries are concentrated in areas of major crude production, such as California, Texas, Louisiana, Oklahoma, Kansas, and in major populated areas such as Illinois, Indiana, Ohio, and Pennsylvania.

ENERGY CONSUMPTION

Petroleum refineries use approximately 3.3×10^{15}Btu of energy annually, about 4% of the total energy consumed in the United States and about 15% of all industrial consumption. Byproduct refinery gas and coke contribute nearly half of the refineries energy requirements, while 24% of their energy needs are required to separate the refinery streams into their basic components. The remainder is used for reforming, hydrogen treating, and alkylation, distributed about 11%, 17%, and 6% respectively.

Refinery energy consumption is highly variable and is dependent on plant size, product, and location. Processing has become more complex, due to the production of more diverse petrochemicals, as plant size has increased, requiring more energy required per unit of product relative to smaller, limited-production plants. The average energy required per unit output has declined about .7% per year from 1962 to a 1971 value of 722,882 Btu/bbl. The increasing price of fuel has lead to more effective use of energy. However, because the growth of capacity is anticipated to be slow, conservation will have to be achieved by retrofitting existing plants and as a result will be more expensive and less effective. During the period from 1971 to 1974, the Bureau of Mines indicated little change within the refinery industry; the reported energy consumption per barrel was essentially constant. Recent efforts to conserve energy appear to be obscured by a significant and approximately equal increase in energy used for additional petroleum refining (to produce higher octane, unleaded, and low sulfur products) and/or protection of the environment.

POINT SOURCES OF WASTE HEAT

The major sources of waste heat in petroleum refineries are: cooling and condensing waters, for heater wall cooling and process stream condensing; stack emissions, from direct fired heaters used for feedstock heating; air cooling of recycle and product streams; and process wastewaters, a minor contribution.

Cooling Waters

The most important method of separating crude petroleum into its product is distillation. Distillation occurs primarily in the fractionation towers where the basic components of the feedstock are separated according to their different vapor pressures. In order to vaporize the various crude components, heat must be applied to the feedstock. This heat is generated in tube-still heaters and steam generating boilers. Nearly all of the energy consumed in the petroleum refining is for feedstock heating and steam generation. Once the different products are extracted from the fractionation towers they are condensed back to their liquid state. Condensing is accomplished by heat transfer to cooling water, air, or raw charging stock. From literature research and industry correspondence, it has been estimated that approximately 1000 gallons of water, at a differential temperature of approximately 23°F, is used for cooling in the refining of one barrel of crude (1.92×10^5Btu/bbl).

Flue Gases

Condensing of process streams is accomplished by heat transfer to water, air, or feedstocks. It has been estimated that about 10% of the waste heat discharged by petroleum refineries was discharged by aircooling of process streams. Flue gases discharged from combustion and other processes are listed in Table 7.

Process Wastewaters

Wastewater, spent acids, spent caustic, and other waste liquid materials are generated by refinery operations. The wastewater is processed through clarification units or gravity separators. The sources of wastes emanating from refinery operations are: wastes containing a principal raw material or product resulting from the stripping of the product from solution; byproducts produced during reactions; spills, slab washdowns, vessel cleanouts, sample point overflows, etc.; cooling towers and boiler blowdown, steam condensate, water treatment wastes, and general washing waters.

Although the intent of this investigation was to identify the quantity and quality of waste heat streams by point source investigations, it was discovered that insufficient quantitative data existed to permit this. The data available on refinery wastewaters apply to the gravity separator effluent,

TABLE 7. TOTAL WASTE HEAT DISCHARGED BY PETROLEUM REFINING (SIC 2911)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($\times 10^9$)	TOTAL Btu AVAILABLE ($\times 10^9$)	% Btu AVAILABLE	% WASTE① HEAT
	FLUE GASES					
BL	Process, NEC③	100-3000	111576.77	56403.72	50.55	8.38
1	Fluid Cracking	110-1500	156904.96	83790.22	53.40	11.79
2	Catalytic Cracking	110-1200	17522.53	11910.68	67.97	1.32
3	Fluid Coking	140-2000	8345.76	7088.26	84.93	0.63
6	Hydrogen Treating	150-1900	56302.20	47498.98	84.36	4.23
7	Chemical Treating	200-1000	3825.79	1763.40	46.09	0.29
8	Physical Treating	110-3500	101530.61	56680.78	55.83	7.63
20	Combustion, Coal	450-740	1220.12	391.83	32.11	0.09
30	Combustion, Coal	690	1020.69	568.91	55.74	0.08
40	Combustion, Coal	750	2497.35	1490.95	59.70	0.19
66	Combustion, Coal	350-1050	9754.71	5932.05	60.81	0.73
70	Combustion, Coal	500	2119.04	756.80	35.70	0.16
99	Combustion, NEC	100-900	100.65	0.00	0.00	0.00
00	Combustion, NEC	240-3000	354629.66	162155.17	45.73	26.65
60	Combustion, Coal	450-580	2469.83	943.31		
	FLUE TOTALS	100-3500	829820.67	437375.05	52.71	62.36
	WASTEWATER					
	Non-Contact Cooling	103	893073.55			67.10
	Process Waters To API Separation	115	38052.70			2.86
	TOTAL WASTEWATERS	95-125	931126.25			69.96
	TOTAL	95-6120	1760946.92	437375.05	24.80	132.32

① Based on purchased fuel & electricity

② Industrial Planning Program (IPP) Process Code for NEDS data, c.f. "OAQPS Guidelines: Aeros Manual Series. Volume 5. Aeros Manual of Codes, "EPA-4-50/2-76-005 (April 1976).

③ "Not Elsewhere Classified"

rather than specific process effluents. Through industry correspondence and literature research, it was estimated that 28 gallons of wastewater, at a temperature range from 105°F to 125°F, are generated in the refining of a single barrel of crude oil. These values represent the average for API separator influent, considering all degrees of integration in refineries.

DISCUSSION - TABLES AND GRAPHS

Table 7 indicates that petroleum refineries reject 132% of their purchased fuels and electricity as waste heat. This is explained by the fact that 50% or more of a petroleum refinery's energy needs are supply by byproduct refinery gas and coke. This energy is not considered purchased product fuels and electricity by the "Annual Survey of Manufacturers". If this energy were considered, petroleum refineries would only discharge roughly 66.3% of the total energy consumed by that industry. Of this waste heat approximately 43% is discharged in non-contact cooling water and air.

Table 8 presents a breakdown, by temperature and EPA region, of the total waste heat discharged by Petroleum refineries. Figure 7 presents a summary of the total waste heat discharged in each EPA region, by petroleum refineries.

Table 8 and Figure 7 indicate that regions 5 and 6 discharge the most significant quantities of waste heat. The combined Btu discharged for these two regions approximates 67% of the total waste heat discharged by petroleum refineries. These two regions contribute almost 61% of the total Btu available, or about 25% of the total discharged.

The waste heat temperature profile, discharged by petroleum refining is presented in Figure 8. This indicates that low temperature cooling streams are a large contributor of the total annual discharge of waste heat to the environment by petroleum refiners.

TABLE 8. REGIONAL WASTE HEAT DISCHARGED BY PETROLEUM REFINING (SIC 2911)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	100	704.30		50.6			
	120	29.90		2.1			
	400	240.59	37.59	17.3	2.7		
	500	274.52	98.04	19.7	7.0		
	520	4.65	1.80	0.3	0.1		
	750	137.10	81.85	9.9	5.9		
TOTALS		1391.06	219.28			0.1	0.1
2	100	37103.00		50.5			
	110	1804.60		2.5			
	120	985.95		1.3			
	150	38.93		0.1			
	180	80.19		0			
	200	0.059		< 0.1			
	250	5.45		< 0.1			
	270	12.70		< 0.1			
	350	1374.69		1.9			
	380	1728.22	172.82	2.4	0.2		
	400	1412.17	220.65	1.9	0.3		
	420	2372.69	488.49	3.2	0.7		
	450	68.13	18.41	0.1	< 0.1		
	470	205.49	63.23	0.3	0.1		
	500	2743.87	979.96	3.7	1.3		
	510	608.61	226.46	0.8	0.3		
	520	190.02	73.41	0.3	0.1		
	530	577.09	230.83	0.8	0.3		
	550	1622.93	690.61	2.2	0.9		
	590	3477.28	1636.37	4.7	< 2.2		
	600	800.83	399.44	1.1	0.5		
	620	172.86	86.43	0.2	0.1		
	630	198.63	101.12	0.3	0.1		
	640	304.78	157.83	0.2	0.2		
	650	829.41	436.53	1.1	0.6		
	680	1090.61	599.83	1.5	0.8		
	690	49.15	27.39	0.1	0.1		
	700	1143.75	645.67	1.6	0.9		
	730	522.58	305.51	0.7	0.4		
	750	286.38	170.98	0.4	0.2		
	770	1472.63	896.38	2.0	1.2		
	790	79.93	49.53	0.1	0.1		
	800	1503.22	939.52	2.0	1.3		
	850	532.36	345.68	0.7	0.5		
	890	266.86	177.90	0.4	0.2		
	900	693.24	464.98	0.9	0/6		

(continued)

TABLE 8. (continued)

EPA REGION #	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGE	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2 (Cont)	930	204.80	139.74	0.3	0.2		
	960	198.24	137.41	0.3	0.2		
	1000	1116.74	789.00	1.5	1.1		
	1100	245.61	180.59	0.3	0.2		
	1120	2195.68	1625.65	3.0	2.2		
	1150	323.98	242.23	0.4	0.3		
	1180	26.46	19.97	<0.1	<0.1		
	1200	3395.67	2577.07	4.6	3.5		
	1600	174.14	143.21	0.2	0.2		
TOTALS		73509.93	16460.87			4.2	0.9
3	100	84599.60		50.6			
	120	3602.70		2.2			
	140	4.85		<0.1			
	346	8.38		<0.1			
	350	60.27		<0.1			
	370	1184.95	81.72	0.7	<0.1		
	400	454.10	70.95	0.3	<0.1		
	430	933.76	213.43	0.6	0.1		
	450	1655.67	447.47	1.0	.3		
	480	161.90	52.61	0.1	0.1		
	500	8303.35	2965.48	5.0	1.8		
	520	5729.33	2213.60	3.4	1.3		
	550	3996.65	1700.70	2.4	1.0		
	560	92.09	40.28	0.1	<0.1		
	570	182.97	82.14	0.1	0.1		
	580	1142.81	525.69	0.7	0.3		
	590	29.09	13.69	0.1	0.1		
	600	11980.10	5759.69	7.2	3.4		
	610	317.93	155.98	0.2	0.1		
	650	869.55	457.66	0.5	0.3		
	670	121.85	66.09	0.1	<0.1		
	690	1316.78	733.95	0.8	0.4		
	700	1404.39	792.80	0.8	0.5		
	710	5431.24	3103.56	3.3	1.9		
	720	1098.89	635.29	0.7	0.4		
	750	4060.00	2423.88	2.4	1.5		
	760	467.80	282.06	2.8	0.2		
	770	3743.59	2278.71	2.2	1.4		
	780	33.14	20.36	<0.1	<0.1		
	790	332.48	206.04	0.2	0.1		
	800	1917.34	1198.34	1.1	0.7		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVIALABLE
3 (Cont)	810	166.78	105.09	0.1	.1		
	820	669.14	424.99	0.4	0.3		
	850	2823.36	1833.35	1.7	1.1		
	900	3580.63	2401.64	2.1	1.4		
	930	1293.74	862.78	0.8	0.5		
	950	3584.70	2472.21	2.1	1.5		
	970	431.96	300.91	0.3	0.2		
	1000	2630.37	1858.42	1.6	1.1		
	1100	211.11	155.23	0.1	0.1		
	1200	1149.26	872.20	0.7	0.5		
	1350	51.44	40.51	<0.1	<0.1		
	1400	154.86	123.18	0.1	0.1		
	1420	4594.60	3668.82	2.8	2.2		
	1500	480.73	389.33	0.3	0.2		
		167061.2	42050.92			9.5	2.4
4	100	53272.2		50.6			
	120	2269.8		2.2			
	200	3.8		<0.1			
	210	3.5		<0.1			
	320	1526.3		1.5			
	330	3725.1		3.5			
	340	20.4		<0.1			
	350	969.9		0.9			
	380	211.7	21.2	0.2	<0.1		
	390	934.5	120.6	0.9	0.1		
	400	24.2	3.8	<0.1	<0.1		
	420	265.8	54.7	0.3	0.1		
	430	364.2	83.2	0.3	0.1		
	450	2765.8	747.5	2.6	0.7		
	460	75.6	21.9	0.1	<0.1		
	470	1293.2	397.9	1.2	0.4		
	480	3773.8	1226.5	3.6	1.2		
	500	434.8	155.3	0.4	0.1		
	520	7.8	3.0	<0.1	<0.1		
	530	39.3	15.7	<0.1	<0.1		
	550	505.5	215.1	0.5	0.2		
	570	848.3	380.9	0.8	0.4		
	580	3.4	1.6	<0.1	<0.1		
	600	70.2	33.8	0.1	<0.1		
	610	4.4	2.2	<0.1	<0.1		
	630	5.0	2.6	0.1	<0.1		
	640	152.7	79.1	0.1	0.1		
	650	12121.9	6379.9	11.5	6.1		
	690	1308.4	729.3	0.1	0.7		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont)	710	5581.5	3189.4	5.3	3.0		
	720	345.5	199.7	0.3	0.2		
	730	32.6	19.0	0.11	0.1		
	740	193.6	144.4	0.2	0.1		
	770	612.4	372.8	0.6	0.4		
	780	626.1	384.6	.6	0.4		
	790	483.6	299.7	0.5	0.3		
	800	216.3	135.2	0.2	0.1		
	810	214.5	135.2	0.2	0.1		
	840	163.7	105.6	0.2	0.1		
	850	1261.9	819.4	1.2	0.8		
	860	136.4	89.2	0.1	0.1		
	870	659.2	433.9	0.6	0.4		
	880	919.4	609.1	0.9	0.6		
	900	1626.0	1090.6	1.5	1.0		
	930	133.3	90.9	0.1	0.1		
	950	937.1	646.2	0.9	0.6		
	970	231.9	161.5	0.2	0.2		
	980	284.4	199.1	0.3	0.2		
	990	735.8	517.5	0.7	0.5		
	1000	188.7	133.3	0.2	0.1		
	1010	187.6	133.2	0.2	0.1		
	1050	621.5	448.5	0.6	0.4		
	1090	363.5	266.3	0.3	0.3		
	1140	570.8	425.4	0.5	0.4		
	1270	524.1	405.2	0.5	0.4		
	1350	285.0	224.4	0.3	0.2		
	1400	77.4	61.6	0.1	0.1		
	2000	6.8	5.8	0.1	0.1		
TOTALS		105222.7	22392.8			6.0	1.3

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5	100	241219.6		50.6			
	120	10276.0		2.2			
	130	27.5		0.1			
	150	39.8		0.1			
	180	10.6		0.1			
	250	619.1		0.1			
	300	274.9		0.1			
	310	55.4		<0.1			
	320	322.6		<0.1			
	330	732.6		0.2			
	340	217.4		0.1			
	350	505.8		0.1			
	370	329.8	22.7	0.1	<0.1		
	380	1750.6	175.1	0.4	<0.1		
	400	4430.2	692.2	0.9	0.2		
	410	282.1	51.3	0.1	<0.1		
	420	983.2	202.4	0.2	<0.1		
	430	491.0	112.2	0.1	<0.1		
	440	3087.9	772.0	0.7	0.2		
	450	6078.9	1643.0	1.3	0.3		
	460	295.9	85.6	0.1	<0.1		
	470	841.3	258.9	0.2	0.1		
	480	858.3	278.9	0.2	0.1		
	490	86.7	29.6	<0.1	<0.1		
	500	7574.3	2705.1	1.6	0.6		
	510	41.2	15.3	<0.1	<0.1		
	520	912.9	352.7	0.2	0.1		
	530	2389.3	955.7	0.5	0.2		
	540	476.9	197.0	0.1	0.1		
	550	3381.0	1438.7	0.7	0.3		
	560	2340.2	1023.8	0.5	0.2		
	570	646.7	290.3	0.1	0.1		
	590	598.5	281.6	0.1	0.1		
	600	58749.8	28245.1	12.3	5.9		
	610	517.7	254.0	0.1	0.1		
	620	28053.7	14026.6	5.9	2.9		
	630	1215.5	618.8	0.3	0.1		
	640	3058.8	1584.0	0.6	0.3		
	650	4026.2	2119.1	0.8	0.4		
	660	691.0	369.3	0.1	0.1		
	670	1116.2	605.4	0.2	0.1		
	680	603.5	331.9	0.1	0.1		
	690	621.9	346.6	0.1	0.1		
	700	3341.5	1886.4	0.7	0.4		
	710	439.2	251.0	0.1	0.1		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	720	1651.3	954.7	0.3	0.2		
	730	190.4	111.3	0.1	0.1		
	740	1881.8	112.0	0.4	0.2		
	750	8976.7	5359.2	1.9	1.1		
	760	1943.4	1171.7	0.4	0.2		
	770	696.4	423.9	0.1	0.1		
	790	541.6	335.6	0.1	0.1		
	800	4575.7	2859.8	1.0	0.6		
	810	363.5	229.0	0.1	0.1		
	820	1154.9	733.9	0.2	0.2		
	830	539.1	345.0	0.1	0.1		
	840	198.2	127.8	<0.1	<0.1		
	850	1935.2	1256.6	0.4	0.3		
	860	4085.8	2671.5	0.9	0.6		
	870	1062.2	699.1	0.2	0.1		
	880	436.3	289.0	0.1	0.1		
	890	530.7	353.8	0.1	0.1		
	900	7277.4	4881.2	1.5	1.0		
	910	1018.2	687.0	0.2	0.1		
	920	904.1	613.5	0.2	0.1		
	930	1180.7	805.6	0.2	0.2		
	950	2353.9	1623.3	0.5	0.3		
	960	133.0	92.2	<0.1	<0.1		
	970	1191.4	829.9	0.3	0.2		
	980	678.5	475.0	0.1	0.1		
	990	175.8	123.6	<0.1	<0.1		
	1000	16438.9	11614.4	3.5	2.4		
	1020	930.8	663.4	0.2	0.1		
	1040	297.5	200.9	0.1	0.1		
	1050	4172.9	3011.4	0.9	0.6		
	1090	535.9	392.6	0.1	0.1		
	1100	4975.2	3658.2	1.0	0.8		
	1150	463.2	346.3	0.1	0.1		
	1170	99.1	74.5	<0.1	<0.1		
	1200	3127.4	2373.4	0.7	0.5		
	1240	137.0	105.1	<0.1	<0.1		
	1300	122.3	95.2	<0.1	<0.1		
	1330	146.4	114.8	<0.1	<0.1		
	1350	167.1	131.6	<0.1	<0.1		
	1360	1045.1	824.7	0.2	0.2		
	1400	1634.2	1299.9	0.3	0.3		
	1450	36.0	28.9	<0.1	<0.1		
	1460	92.2	74.2	<0.1	<0.1		
	1500	548.6	444.3	0.1	0.1		
	1600	500.8	411.9	0.1	0.1		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	1650	112.5	931.1	<0.1	<0.1		
	3000	140.3	127.3	<0.1	<0.1		
	3500	455.9	419.9	0.1	0.1		
TOTALS		476450.6	117894.1			27.0	6.7
6	100	359553.2		50.6			
	110	15296.9		2.2			
	120	9587.9		1.4			
	140	1.0		<0.1			
	150	92.9		<0.1			
	180	86.3		<0.1			
	200	68.8		<0.1			
	230	2.5		<0.1			
	250	2670.0		0.4			
	270	11.1		<0.1			
	300	3076.9		0.4			
	310	822.0		0.1			
	320	338.7		<0.1			
	330	7.1		<0.1			
	340	1719.5		0.2			
	350	7180.9		1.0			
	360	1101.7	39.3	0.2	<0.1		
	370	576.6	39.8	0.1	<0.1		
	380	517.3	51.7	0.1	<0.1		
	390	879.4	113.5	0.1	<0.1		
	400	33211.7	5189.3	4.7	0.7		
	410	.3	0.1	<0.1	<0.1		
	420	36.4	7.5	<0.1	<0.1		
	440	274.0	68.5	<0.1	<0.1		
	450	2046.9	553.2	0.3	0.1		
	460	4540.6	1314.4	0.6	0.2		
	470	3340.5	1027.9	0.5	0.1		
	480	1259.0	409.2	0.2	0.1		
	490	272.6	93.1	<0.1	<0.1		
	500	110298.8	3939.2	1.6	0.6		
	510	3459.0	1287.1	0.5	0.2		
	520	1810.2	699.4	0.3	0.1		
	530	3490.2	1396.1	0.5	0.2		
	540	1300.1	537.1	0.2	0.1		
	550	8664.6	3687.1	1.2	0.5		
	560	3832.1	1676.6	0.5	0.2		
	570	1960.2	880.1	0.3	0.1		
	580	2710.2	1246.7	0.4	0.2		
	590	455.7	214.5	0.1	<0.1		
	600	7226.7	3474.4	1.0	0.5		
	610	528.8	259.4	0.1	<0.1		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6 (Cont)	620	1457.3	728.6	0.2	0.1		
	630	300.6	153.0	<0.1	<0.1		
	640	567.0	293.6	0.1	<0.1		
	650	3790.3	1994.9	0.5	0.3		
	660	2686.7	1437.0	0.4	0.2		
	670	908.8	492.9	0.1	0.1		
	680	2145.1	1179.8	0.3	0.2		
	690	232.5	129.6	<0.1	<0.1		
	700	36715.2	20726.3	5.2	2.9		
	710	4136.8	2363.9	0.6	0.3		
	720	2123.5	1227.6	0.3	0.2		
	730	4107.0	2401.0	0.6	0.3		
	740	2048.3	1210.4	0.3	0.2		
	750	4157.7	2482.2	0.6	0.3		
	760	1069.8	645.0	0.2	0.1		
	770	445.5	271.2	0.1	<0.1		
	780	2212.5	1359.1	0.3	0.2		
	790	1212.9	751.7	0.2	0.1		
	800	10407.2	6504.5	1.5	0.9		
	810	1867.1	1176.6	0.3	0.2		
	820	3653.1	2320.2	0.5	0.3		
	830	1303.2	885.3	0.2	0.1		
	840	1105.0	712.4	0.2	0.1		
	850	6983.9	4535.0	1.0	0.6		
	860	3239.0	2117.8	0.5	0.3		
	870	2225.0	1464.6	0.3	0.2		
	880	909.7	602.7	0.1	0.1		
	890	656.3	437.6	0.1	0.1		
	900	9337.8	6263.1	1.3	0.9		
	910	232.1	156.6	<0.1	<0.1		
	920	2759.4	1872.8	0.4	0.3		
	930	1624.8	1108.7	0.2	0.2		
	940	915.1	627.8	0.1	0.1		
	950	136.1	93.8	<0.1	<0.1		
	960	258.3	179.1	<0.1	<0.1		
	970	887.8	618.5	0.1	0.1		
	980	635.0	444.5	0.1	0.1		
	990	226.7	159.5	<0.1	<0.1		
	1000	11022.6	7787.7	1.6	1.1		
	1010	312.8	222.0	<0.1	<0.1		
	1020	39.1	27.9	<0.1	<0.1		
	1030	398.4	285.2	0.1	0.1		
	1050	3431.3	2476.2	0.5	0.3		
	1070	438.3	318.8	0.1	<0.1		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6 (Cont)	1100	7880.0	5794.1	1.1	0.8		
	1110	1077.7	795.2	0.2	0.1		
	1130	7.5	5.6	<0.1	<0.1		
	1140	2341.7	1745.2	0.3	0.2		
	1150	2148.4	1606.3	0.3	0.2		
	1170	1982.0	1491.0	0.3	0.2		
	1180	156.5	118.0	<0.1	<0.1		
	1190	295.2	223.4	<0.1	<0.1		
	1200	7628.5	5789.5	1.1	0.8		
	1210	190.9	145.3	<0.1	<0.1		
	1240	805.3	617.8	0.1	0.1		
	1250	4020.7	3092.8	0.6	0.4		
	1260	175.8	135.6	<0.1	<0.1		
	1320	195.7	153.1	<0.1	<0.1		
	1350	186.7	147.0	<0.1	<0.1		
	1390	208.4	165.5	<0.1	<0.1		
	1400	317.1	252.2	<0.1	<0.1		
	1420	197.2	157.5	<0.1	<0.1		
	1500	656.2	531.5	0.1	0.1		
	1600	6.8	5.6	<0.1	<0.1		
	1640	386.3	319.4	0.1	0.1		
	1700	14938.3	12448.6	2.1	1.8		
	1750	2592.0	2172.9	0.4	0.3		
	1800	263.2	221.9	<0.1	<0.1		
	1900	38398.1	32701.6	5.4	4.6		
	2300	9.9	8.7	<0.1	<0.1		
	3000	2240.7	2033.5	0.3	0.3		
TOTALS		710161.9	184329.5			40.3	10.4
7	100	98512.2		50.6			
	110	418.1		2.2			
	120	261.6		1.4			
	310	181.1		0.9			
	320	307.8		1.6			
	330	165.4		0.9			
	520	2720.9	1051.3	14.0	5.4		
	530	868.1	347.2	4.5	1.8		
	650	129.4	68.1	0.7	0.4		
	680	24.7	13.6	0.1	0.1		
	690	1544.4	860.8	8.0	4.4		
	800	1322.6	826.6	6.8	4.3		
	1000	1884.1	1331.1	9.7	6.9		
TOTALS		19381.1	4498.7			1.1	0.3

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
8	100	41039.8		50.6			
	120	1748.5		2.2			
	250	69.6		0.1			
	300	76.6		0.1			
	340	161.6		0.2			
	370	4.6	0.3	<0.1	<0.1		
	380	352.4	35.2	0.4	<0.1		
	400	3145.9	491.5	3.9	0.6		
	420	111.3	22.9	0.1	<0.1		
	430	143.5	32.8	0.2	<0.1		
	440	439.0	109.7	0.5	0.1		
	450	398.0	107.6	0.5	0.1		
	470	74.7	23.0	0.1	<0.1		
	490	89.4	30.5	0.1	<0.1		
	500	435.1	155.4	0.5	0.2		
	520	502.4	194.1	0.6	0.2		
	530	126.4	50.6	0.2	0.1		
	540	247.7	102.3	0.3	0.1		
	550	657.0	279.6	0.8	0.3		
	560	1089.7	476.8	1.3	0.6		
	570	144.0	64.6	0.2	0.1		
	580	50.7	23.3	0.1	<0.1		
	600	1860.0	894.3	2.3	1.1		
	620	231.2	115.6	0.3	0.1		
	630	14.5	7.4	<0.1	<0.1		
	650	4707.0	2477.4	5.8	3.1		
	660	636.9	340.4	0.8	0.4		
	670	636.7	345.3	0.8	0.4		
	680	60.9	33.5	0.1	0.1		
	690	10.2	5.7	<0.1	<0.1		
	700	3107.2	1754.1	3.8	2.2		
	740	232.2	131.9	0.3	0.2		
	750	1767.3	1055.1	2.2	1.3		
	760	169.1	101.9	0.2	0.1		
	780	592.9	364.2	0.7	0.4		
	800	1033.9	646.2	1.3	0.8		
	810	333.2	209.9	0.4	0.3		
	840	1737.1	1119.9	2.1	1.4		
	850	670.1	453.2	0.8	0.5		
	870	135.3	89.1	0.2	0.1		
	880	125.9	83.4	0.2	0.1		
	900	1282.5	860.2	1.6	1.1		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
8	910	14.3	9.6	<0.1	<0.1		
	920	1297.6	880.5	1.6	1.1		
	930	195.3	133.3	0.2	0.2		
	940	8.9	6.1	<0.1	<0.1		
	950	3062.3	2111.9	3.8	2.6		
	960	255.5	177.1	0.3	0.2		
	970	1709.9	1191.2	2.1	1.5		
	980	115.0	80.5	0.1	0.1		
	1000	281.7	199.0	0.3	0.2		
	1010	182.5	129.5	0.2	0.2		
	1050	641.7	463.1	0.8	0.6		
	1080	249.8	182.3	0.3	0.2		
	1100	885.4	651.1	1.1	0.8		
	1120	1.7	1.3	<0.1	<0.1		
	1200	193.1	146.5	0.2	0.1		
	1210	306.1	233.0	0.4	0.3		
	1250	98.2	75.5	0.1	0.1		
	1260	86.9	67.1	0.1	0.1		
	1300	619.2	482.1	0.8	0.6		
	1360	53.5	42.2	0.1	0.1		
	1370	87.9	69.5	0.1	0.1		
	1500	102.7	83.2	0.1	0.1		
	2740	169.2	152.1	0.2	0.2		
TOTALS		81061.3	20838.7			4.6	1.2
9	100	50607.9		50.6			
	120	2156.0		2.2			
	140	31.9		0.1			
	230	531.7		0.5			
	240	193.1		0.2			
	270	36.5		0.1			
	290	396.5		0.4			
	300	1093.7		1.1			
	310	191.3		0.2			
	320	795.9		0.8			
	350	293.0		0.3			
	360	251.2	9.0	0.3	<0.1		
	370	56.0	3.9	0.1	<0.1		
	380	781.3	78.1	0.8	0.1		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
9 (Cont)	390	710.4	91.7	0,7	0,1		
	400	65.4	10.2	0.1	<0.1		
	410	267.4	48.6	0.3	<0.1		
	440	474.0	118.5	0.5	0.1		
	480	289.4	94.1	0.3	0.1		
	490	568.3	194.0	0.6	0.2		
	500	7385.5	2637.7	7.4	2.6		
	520	388.3	150.0	0.4	0.2		
	530	1237.0	494.8	1.2	0.5		
	540	1607.1	701.0	1.7	0.7		
	550	860.9	366.3	0.9	0.4		
	570	2037.5	914.8	2.0	0.9		
	580	2958.7	1361.0	3.0	1.4		
	600	2275.6	1094.0	2.3	1.1		
	650	1478.9	778.4	1.5	0.8		
	680	69.9	38.5	0.1	<0.1		
	690	843.6	470.2	0.8	0.5		
	700	2456.0	1386.5	2.5	1.4		
	750	853.0	509.3	0.9	0.5		
	800	13178.1	8236.3	13.2	8.2		
	820	335.9	213.3	0.3	0.2		
	850	104.9	68.1	0.1	0.1		
	860	24.3	15.9	<0.1	<0.1		
	910	215.4	145.4	0.2	0.1		
	980	792.8	554.9	0.8	0.6		
	1100	265.5	195.3	0.3	0.2		
	1500	710.8	575.7	0.7	0.6		
TOTALS		99959.9	21555.4			5.7	1.2
10	100	15198.6		50.6			
	120	646.9		2.2			
	290	90.5		0.3			
	300	163.6		0.5			
	400	78.3	12.2	0.3	0.1		
	430	614.2	140.4	2.0	0.5		
	440	107.1	26.8	0.4	0.1		
	520	523.2	202.2	1.7	0.7		
	590	1090.6	513.2	3.6	1.7		

TABLE 8. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
10 (Cont)	600	4398.2	2114.5	14.7	7.0		
	640	1099.6	569.4	3.7	1.9		
	670	118.1	64.1	0.4	0.2		
	680	1577.0	867.3	5.3	2.9		
	690	145.6	81.2	0.5	0.3		
	710	180.5	103.1	0.6	0.3		
	730	404.0	236.2	1.3	0.8		
	760	200.7	121.0	0.7	0.4		
	780	2207.8	1356.2	7.4	4.5		
	890	728.9	485.9	2.4	1.6		
	950	446.4	307.9	1.5	1.0		
TOTALS		30019.5	7201.7			1.7	0.4

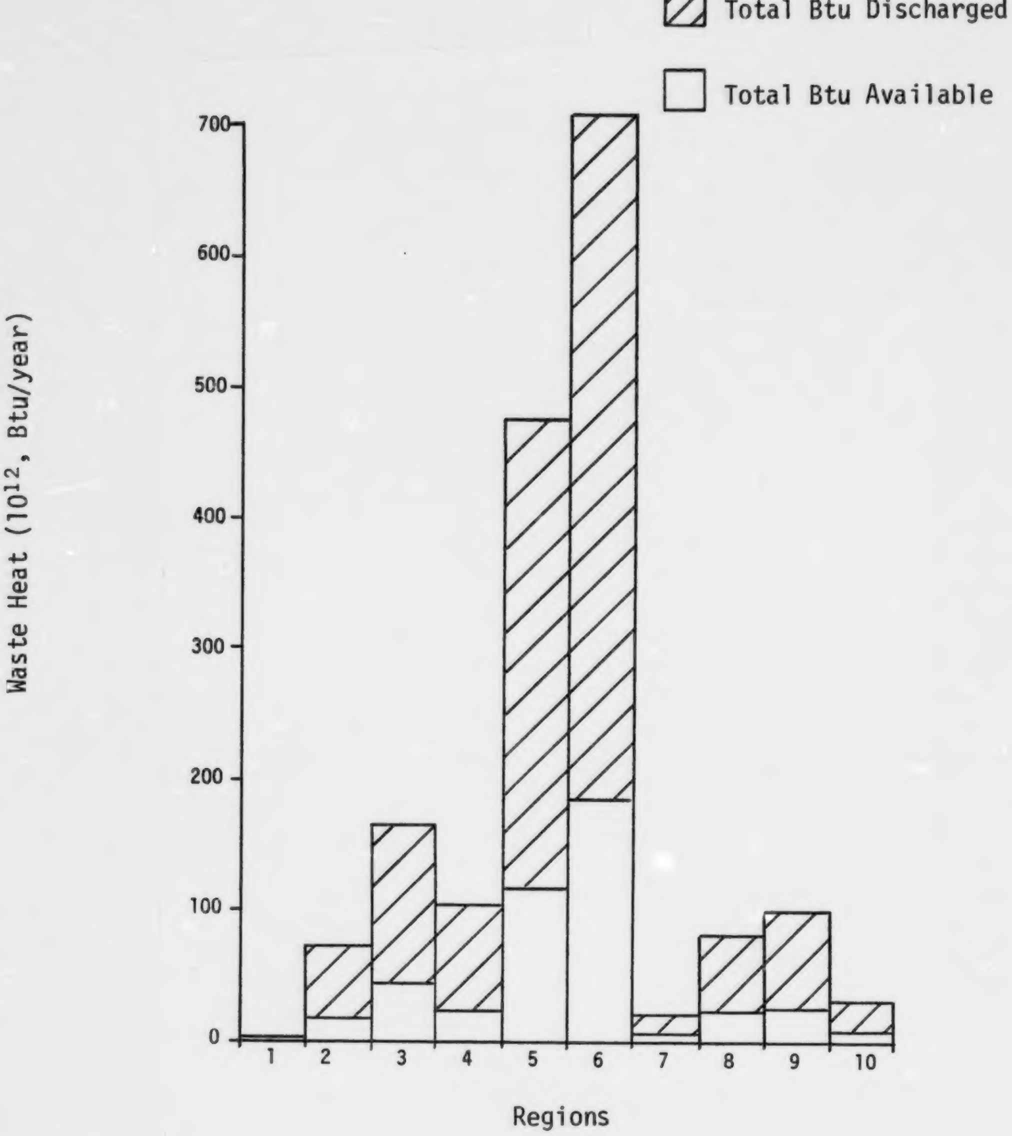

Figure 7. Regional totals for Petroleum Refining (SIC 2911).

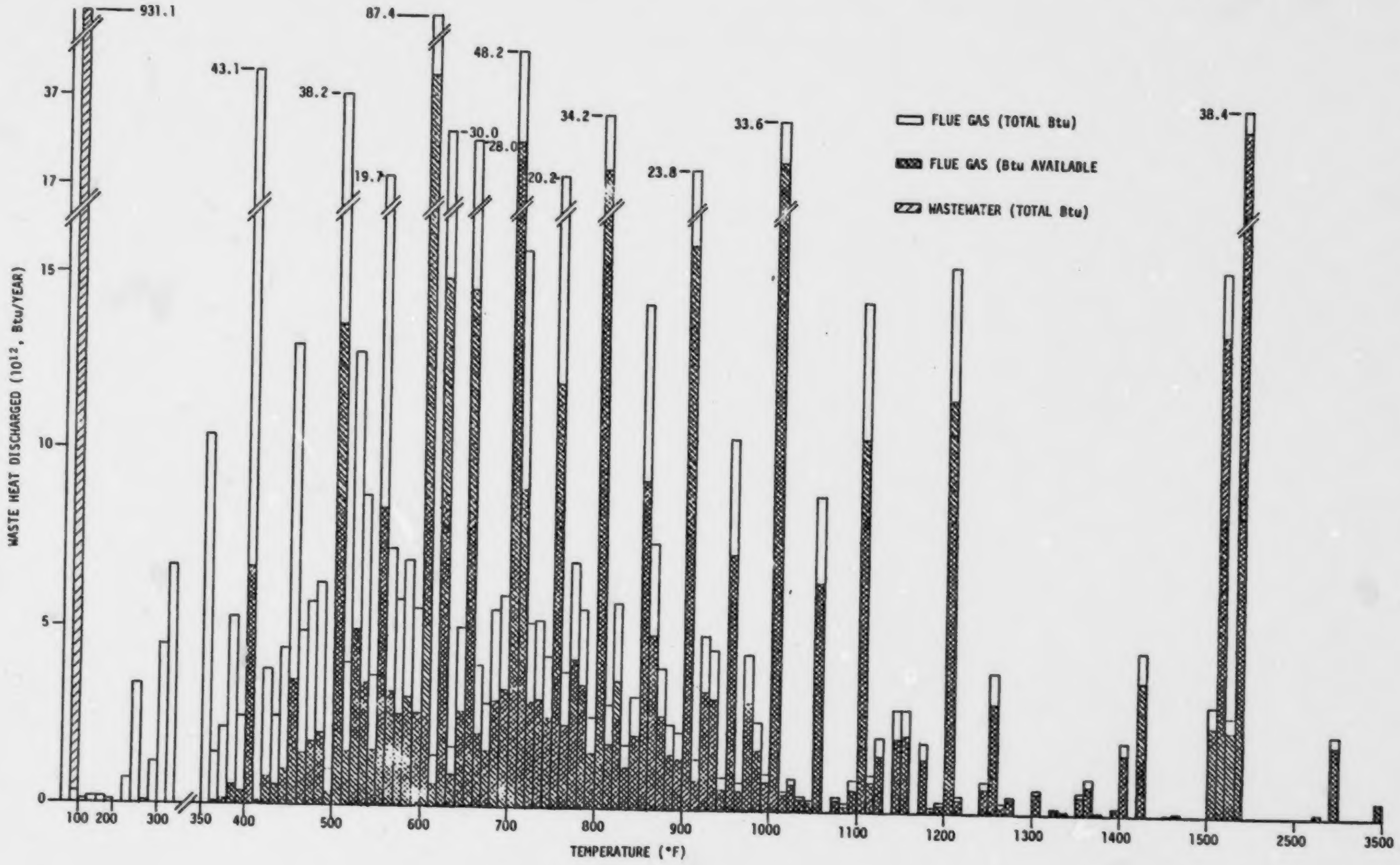

Figure 8. Waste heat temperature profile for Petroleum Refining (SIC 2911).

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SECTION 4

PRIMARY METALS

IRON AND STEEL (SIC 3312)

General Description

The iron and steel industry is defined as those establishments primarily engaged in manufacturing hot metal, pig iron, silvery pig iron, and ferro-alloys, from iron ore, iron and steel scrap; converting pig iron, scrap iron and scrap steel into steel; and in hot rolling iron and steel into basic shapes such as plates, sheets, strips, rods, bars and tubing. Merchant blast furnaces and byproduct or beehive coke ovens are included in SIC 3312.

Year-to-year production of raw steel has fluctuated widely over the past 15 years, the average annual growth rate has been about 2.5%. Normally the actual productive output of raw steel is well under the rated productive capacity, generally in the range of 60% to 70%. In recent years, the actual output has moved closer to the rated capacity, being about 74% in 1972 and about 83% in 1973, based on estimated raw steel capacity of 180 million tons. Industry sources have projected steel production to continue increasing from 2% to 3% annually and at this rate should reach approximately 175 x 10^6 tons in 1980. Most of the increase in capacity has been accomplished by upgrading capacities of existing steel plants, building larger furnaces, and replacement of open hearths with basic oxygen furnaces.

Geographical Distribution

The steel industry comprises some 400 steel production and fabrication plants and is second only to the automotive industry in number of employees. About 130 of these plants producted a total of 146 million short tons of raw steel in 1974. These plants are located in almost every state but the principal concentrations are in the northeast quadrant of the country, in the states of Pennsylvania, Ohio, Indiana, and Illinois. This area of the United States contains abundant raw materials, such as coal, and large steel consuming industries, which decreases transportation costs of raw materials and products shipped and hence influenced the industry's geographical distribution.

Energy Consumption

The United States steel industry uses about 6% of all energy consumed in the nation and 17% of the total industrial energy requirements. About 23 x 10^6Btu are consumed in the production of raw steel. Thus, the total energy consumption required to produce an estimated 165 million tons in 1977 would be 3.795 x 10^{15}Btu.

Coal is the major fuel consumed in the steel industry. In 1974, about 90 million tons of coal were consumed for the preparation of coke, of which 99% was produced in byproduct coke plants. In addition to coal, the industry purchased natural gas, electricity, and fuel oil.

During the past fifteen to twenty years, major technological changes have taken place in the steel industry. These changes led to markedly increased efficiencies of production equipment and to significant savings in raw materials and energy used per unit of output. Improvements have particularly occurred in the following processes: better charge preparation and fuel injection for blast furnaces; development of continuous processes for casting, rolling and finishing of steel; and development of the topblown oxygen converter process. In the period from 1967 to 1980, energy utilization per unit of output was expected to decrease at an average annual rate of 0.8%. If this is accomplished the energy that would be consumed in 1977 to produce 165 million tons would approximate 3.675 quads.

Point Sources of Waste Heat

The major process steps in iron and steelmaking are; agglomeration of iron ore, coke making, blast furnace production of pig iron, refining of pig iron in steel making furnaces, and casting. The solidified product is then heated, rolled, and heat treated to form a wide variety of products. In 1974 about 80% of the raw steel was produced from iron ores and scrap charges to the basic oxygen and open-hearth furnaces, and 20% was produced in the scrap charge electric furnaces.

The major sources of waste heat in the industry are: noncontact cooling waters from furnaces, hood systems, annealing furnaces; stack gases from coking, blast, steel, soaking and reheat operations; and contact cooling and process waters.

Non-Contact Cooling Waters

Non-contact cooling waters are those waters used for cooling purposes which do not come into contact with the product or byproducts and are discharged or recycled without degradation of the initial water quality other than an elevation in temperature. These cooling waters are utilized primarily to prevent furnace, hood system, and equipment, from overheating.

As a general rule, the quality of water used for process and noncontact cooling is not critical. The industry is presently using river, lake, well, impounded, and brackish waters, for noncontact cooling purposes with no major problems.

In order to establish the noncontact cooling water requirements for making steel, the water system of an integrated mill producing 3 million ingot tons per year and incorporating a high degree of water recycle was considered. The plant consisted of the following production units: 1) coke plants,

2) blast furnace, 3) boiler and powerhouse, 4) basic oxygen shop, 5) open hearth shop and 6) rolling and finishing mills. The non-contact cooling water requirements for these process units were determined for a plant with an average daily production rate of 8,219 ingot tons of steel. This indicated that 164.4 x 10^6 gallons per day of non-contact cooling water are required, or about 2,000 gallons of non-contact cooling water are required to produce 1 ingot ton of steel. Table 9 presents the breakdown of the water usage per production unit.

These quantities of water usage were taken from steel plants known to have better than average water use practices and might well represent the lower limit of the water used for these purposes.

Production from electric furnaces contributed about 20% of the steel produced in the United States and cooling water requirements were estimated to be 1300 gallons per ton of steel, with a differential temperature of 30°F. This equates to roughly 325,000 Btu per ton of electrically refined steel.

Vacuum degassing and continuous casting cooling water requirements were not included with rolling and finishing mills on Table 9. Vacuum degassing and continuous casting utilizes about 130 gallons per ton, with a differential temperature of 15°F, and 1800 gallons per ton with a differential temperature of 12°F, respectively. Their outputs represent about 10% of the steel produced in the United States and the waste heat generated is 196,500 Btu per ton of steel produced by these techniques.

Contact Cooling and Process Waters

As defined by this report, contact cooling waters are those waters which come into direct contact with any product from a process. Process waters are those waters primarily used for direct contact offgas washing and cooling.

When the coking operation is complete, the hot coke is pushed from the oven into a quench car where it is cooled by water sprays. The quenching of coke requires about 500 gallons per ton. Approximately 30% of this is evaporated by the hot coke and discharged from the quench tower as steam.

TABLE 9. WATER CONSUMPTIONS PER TON

	Gallon/Ingot Ton of Steel	Avg. ΔT	Btu/Ton
Coke Plant	3,154	20	526,400
Blast Furnace	3,686	10	307,600
Boiler and Powerhouse	4,378	20	730,600
Basic Oxygen Furnace	1,754	25	365,900
Open Hearth	1,679	30	420,300
Rolling & Finishing Mills	5,200	16	694,000
Total			3,045,100

In the agglomeration operation, gas scrubbers are used which contribute to the process wastewater load. In most plants these waters are combined with blast furnace process waters and in this report will be treated as such.

Blast furnace and sinter plant process waters are treated via thickening to remove suspended solids. The mean flow and temperature out of the thickener are 3400 gallons/ton and 110°F respectively. Thickeners effluent discharges approximately 851,200 Btu/ton of waste heat. Effluents from the treatment systems are listed in Table 10.

During vacuum degassing, approximately 580 gallons of condensed steam and heated cooling water are discharged from the barometric condenser into a hot well. This effluent has a differential temperature of 35°F which equates to 169,400 Btu per ton of vacuum degassed steel.

The continuous casting spray water system discharges into an open recirculating system, which utilizes either settling chamber scale pits or flat bed type filters to effect scale and oil removal. This contributed approximately 560 gallons, with a differential temperature of 45°F, of effluent containing 210,300 Btu of waste heat for every ton of continuously coated steel. In the rolling and finishing operations, descaling and contact cooling waters are discharged to scale pits. Much of this water is evaporated, but not enough data was available to estimate the Btu losses. The remaining waters which collect in the scale pits are at relatively low temperatures and high in pollutants, particularly oil and scale.

Flue Gases and Other Atmospheric Discharges

In the steel industry there are quite a variety of coal combustion processes which may serve different functions: Boilers may serve in coking operations, or as blast, soaking, reheat and annealing furnaces. However, in Table 11 the coal fired processes were not listed by their type, but by the furnaces' heating rate. All other combustion waste gases which were listed under combustion offgases, and did not have a process code number, were listed under Process NEC.

TABLE 10. STEELMAKING OPERATIONS EFFLUENTS

	Production (Tons)	Mean Flow Rates Gallons/Ton	Average Temperature	Percent Use of Wet and Semi-Wet Systems
Basic Oxygen Furnace	74,615	490	35°F	87%
Open Hearth Furnace	35,042	560	40°F	39%
Electric Furnace	23,584	235	10°F	28%

TABLE 11. TOTAL WASTE HEAT DISCHARGED BY BLAST FURNACES AND STEEL MILLS (SIC 3312)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($\times 10^9$)	TOTAL Btu AVAILABLE ($\times 10^9$)	% Btu AVAILABLE	% WASTE HEAT ①
	FLUE GASSES					
BL	Process, NEC	100-2000	91589.80	44666.69	48.77	6.73
1	Coking, Unloading	120-2650	57943.48	26617.32	45.94	4.26
2	Coking, Charging	110-550	15743.28	4831.70	30.69	1.16
3	Coking, Cycle	100-1200	15719.72	481.37	3.06	1.15
4	Coking, Discharging	100-1800	73483.36	37258.22	50.70	5.40
5	Coking, Quenching	100-3000	32444.58	13784.47	42.47	2.38
6	Coking, Underfiring	100-1350	131091.12	51854.82	39.55	9.63
8	Ore Charge	110-800	2070.79	770.67	37.21	0.15
9	Agglomerates Charge	110-300	341.76	0.00	0.00	0.03
10	Combustion, Coal	110-360	683.18	22.82	3.34	0.05
20	Combustion, Coal	300-650	27044.40	5104.13	18.87	1.99
46	Combustion, NEC	500	1575.75	562.77	35.71	0.12
50	Combustion, Coal	360	800.65	28.59	3.57	0.06
60	Combustion, Coal	110-1800	1521.85	411.07	27.01	0.11
70	Combustion, Coal	400-440	491.55	98.51	20.04	0.04
80	Combustion, Coal	290-700	13774.50	5625.86	40.84	1.01
90	Combustion, Coal	650	844.61	444.53	52.63	0.06
99	Combustion, NEC.	320-380	5.25	0.10	1.90	0.00
00	Combustion, NEC	100-1910	207676.81	117062.01	56.37	15.26
	FLUE TOTAL	100-2650	674846.44	309625.65	45.88	49.58
	WASTEWATER					
	N-C Cooling	100	86790			6.30
	Gas-Scrubbers	110	140415			10.20
	N-C Cooling	90	50350			3.68
	N-C Cooling	105	60390			4.39
	N-C Cooling	110	69300			5.04
	N-C Cooling	116	64350			4.68
	Gas-Scrubbers	115	23595			1.72
	Gas-Scrubbers	120	30855			2.24
	Gas-Scrubbers	90	3234			0.24
	N-C Cooling	101	114510			8.33
	N-C Cooling	95	2689			0.20
	Contact Cooling	115	27885			2.03
	N-C Cooling	92	29700			2.16
	Contact Cooling	125	34965			2.54
	TOTAL WASTEWATERS	90-125	739335	-	-	53.80
	TOTAL	90-2650	1414181.44	309625.65	22.50	103.00

① Based on purchased fuel & electricity

② NEDS data, EPA/2-76-005 guidelines

Discussion - Tables and Graphs

Table 11 presents a summary of the total waste heat discharged by Blast Furnaces and Steel Mills, SIC 3312. This table indicates that 103% of the energy contained in purchased fuels and electricity is discharged as waste heat into the environment. This number exceeds 100% because the energy contained in coal used as feedstock for coking operations is not considered purchased fuels and electricity in the Survey of Manufacturers.

This table also indicates the 52% of the waste heat, discharged by this industry, results from the coking and steelmaking operations. Wastewaters are the largest contributor of waste heat discharge in almost 54% of the total waste heat discharged. This represents a significant quantity of low-grade waste heat while high-grade waste heat (i.e., Btu available) account for only 22.5% of the total waste heat discharged.

Table 12 presents a breakdown, by temperature and EPA regions, of the total waste heat discharged by Blast Furnaces and Steel Mills, SIC 3312.

Figure 9 presents a summary of the waste heat discharged in each EPA region. This indicates that region 5 discharged twice as much waste heat as the combined total of the other EPA regions.

The waste heat temperature profile for this industry is presented in Figure 10. This indicates that the largest waste heat discharges are discharged by wastewater streams with differential temperatures of from 10°F to 50°F. Other significant quantities of waste heat are discharged by flue gases at 450°F, 500°F, and 800°F.

TABLE 12. REGIONAL WASTE HEAT DISCHARGED BY BLAST FURNACES AND STEEL MILLS (SIC 3312)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	90	302.8		5.9			
	100	738.4		14.4			
	110	977.8		19.1			
	120	584.8		11.4			
	130	126.6		2.4			
	150	4.4		0.1			
	290	1461.5		28.5			
	1480	925.4	746.9	18.1	14.6		
TOTAL		5121.7	746.9			0.4	0.1
2	90	4925.4		5.9			
	100	12043.0		14.4			
	110	15297.3		19.1			
	120	8643.3		10.4			
	130	2763.9		3.3			
	150	1093.8		1.3			
	200	137.7		0.2			
	210	0.1		0.1			
	240	100.8		0.1			
	250	892.3		1.1			
	270	175.5		0.2			
	300	13.7		0.1			
	350	1197.8		1.4			
	440	636.2	159.0	0.8	0.2		
	450	3253.6	879.4	3.9	1.1		
	460	96.7	28.0	0.1	0.1		
	500	3951.0	1411.1	4.7	1.7		
	550	168.0	71.5	0.2	0.1		
	600	1494.6	718.5	1.8	0.9		
	620	3012.0	1506.0	3.6	1.8		
	650	1203.2	633.3	1.4	0.8		
	660	3.0	1.6	0.1	0.1		
	700	275.0	155.2	0.3	0.2		
	850	878.2	570.2	1.1	0.7		
	870	1624.4	1069.2	1.9	1.3		
	900	22.7	15.2	0.1	0.1		

(continued)

TABLE 12. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2 (Cont)	980	140.3	98.2	0.2	0.1		
	1000	5378.8	3800.2	6.5	4.6		
	1400	6227.0	4953.3	7.5	5.9		
	1600	67.3.2	5520.7	8.1	6.6		
	1800	395.7	333.6	0.5	0.4		
TOTAL		83388.3	21924.4			5.9	1.6
3	90	12333.5		5.9			
	100	30484.4		14.6			
	110	40375.5		19.3			
	120	21877.2		10.5			
	130	5328.6		2.6			
	140	448.4		0.2			
	150	4738.2		2.3			
	170	62.0		0.1			
	180	449.3		0.2			
	190	1.2		0.1			
	200	758.1		0.4			
	210	408.4		0.2			
	220	2.7		0.1			
	230	20.9		0.1			
	240	2425.6		1.2			
	250	1141.4		0.5			
	270	1184.2		0.6			
	280	418.8		0.2			
	290	243.4		0.1			
	300	97.0		0.1			
	320	9.5		0.1			
	330	1216.5		0.6			
	350	6254.9		3.0			
	360	1439.8	51.4	0.7	0.1		
	400	5892.7	920.7	2.8	0.4		
	410	334.4	60.8	0.2	0.1		
	420	171.9	35.4	0.1	0.1		
	450	3828.8	1034.8	1.8	0.5		
	460	230.2	66.6	0.1	0.1		
	500	9677.6	3456.3	4.6	1.7		
	510	274.7	102.2	0.1	0.1		
	530	587.3	234.9	0.3	0.1		
	550	4982.6	2120.3	12.0	1.0		
	600	3666.1	1762.6	1.8	0.8		
	620	431.6	215.8	0.2	0.1		
	650	2787.0	1466.8	1.3	0.7		
	660	734.4	391.4	0.4	0.2		
	670	6551.7	3553.5	3.1	1.7		
	700	863.4	487.4	0.4	0.2		
	720	682.0	394.3	0.3	0.2		
	740	622.2	367.6	0.3	0.2		
	750	878.4	524.4	0.4	0.3		

TABLE 12. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
3 (Cont)	760	866.8	533.6	0.4	0.3		
	800	19006.1	11878.8	9.1	5.7		
	830	2357.2	1508.6	1.1	0.7		
	840	1985.9	1280.4	1.0	0.6		
	850	1875.4	1217.8	0.9	0.6		
	900	312.6	209.7	0.1	0.1		
	1000	1223.0	864.1	0.6	0.4		
	1100	301.3	221.5	0.2	0.1		
	1200	921.5	699.4	0.4	0.3		
	1300	443.6	345.4	0.2	0.2		
	1320	489.2	382.7	0.2	0.2		
	1350	623.2	490.7	0.3	0.2		
	1500	24.1	19.5	0.1	0.1		
	1600	185.6	152.6	0.1	0.1		
	1700	826.4	688.7	0.4	0.3		
	1800	202.3	170.6	0.1	0.1		
	1950	138.8	118.8	0.1	0.1		
	2000	129.7	111.5	0.1	0.1		
	2650	1834.3	1641.6	5.7	0.8		
TOTALS		208660.6	39772.4			14.8	2.8
4	90	2555.3		5.9			
	100	8981.0		14.4			
	110	12078.5		19.4			
	120	6510.6		10.5			
	130	1538.7		2.4			
	140	0.6		0.1			
	150	140.2		0.2			
	160	162.2		0.3			

TABLE 12. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont.)	170	270.1		0.4			
	180	204.8		0.3			
	250	58.6		0.1			
	270	52.0		0.1			
	300	1658.0		2.7			
	310	90.0		0.1			
	320	2.3		0.1			
	350	1.4		0.1			
	370	383.5	27.1	0.6	0.1		
	400	4123.4	644.3	6.6	1.0		
	450	3550.0	959.5	5.7	1.5		
	460	93.3	27.0	0.1	0.1		
	490	889.5	303.7	1.4	0.5		
	500	1216.4	434.4	2.0	0.7		
	550	117.9	50.2	0.2	0.1		
	570	370.4	166.3	0.6	0.3		
	600	3074.8	1478.3	4.9	2.4		
	800	483.0	301.9	0.8	0.5		
	900	2220.8	1489.5	3.6	2.4		
	1200	2004.8	1521.5	3.2	2.4		
	1500	543.7	440.3	0.9	0.7		
	1800	126.3	106.4	0.2	0.2		
	3000	7598.6	6896.0	12.2	11.1		
TOTALS		62233.8	14846.5			4.4	1.1
5	90	55317.3		5.9			
	100	135153.3		14.4			
	110	179399.7		19.2			
	120	97971.8		10.5			
	130	23353.4		2.5			
	140	297.7		0.1			
	150	541.9		0.1			
	160	657.0		0.1			
	170	3596.2		0.4			
	180	33.7		0.1			
	190	1061.3		0.1			
	200	6472.4		0.7			
	220	2734.8		0.3			
	250	643.6		0.1			
	260	3977.3		0.4			
	270	989.8		0.1			
	280	1230.5		0.1			
	300	14650.2		1.6			
	310	117.6		0.1			
	320	3812.8		0.4			

TABLE 12. (continued)

EPA REGION#	TEMP. (•F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	330	571.2		0.1			
	350	205.9		0.1			
	360	628.8	22.5	0.1	0.1		
	380	24819.0	2481.9	2.7	0.3		
	400	9524.6	1488.2	1.0	0.2		
	410	338.5	61.5	0.1	0.1		
	420	3244.3	667.9	0.3	0.1		
	430	3328.1	760.7	0.4	0.1		
	440	8758.1	2189.5	0.9	0.2		
	450	43524.8	11763.5	4.7	1.3		
	470	929.6	286.0	0.1	0.1		
	490	852.1	291.0	0.1	0.1		
	500	32132.5	11475.9	3.4	1.2		
	510	849.8	316.2	0.1	0.1		
	520	2617.5	1011.3	0.3	0.1		
	530	614.0	245.6	0.1	0.1		
	540	1852.1	765.0	0.2	0.1		
	550	12178.8	5182.5	1.3	0.6		
	560	11430.8	5001.0	0.1	0.5		
	570	2251.2	1010.7	0.3	0.1		
	600	15729.0	7592.3	1.7	0.8		
	610	1363.1	668.7	0.2	0.1		
	620	1097.4	548.7	0.1	0.1		
	630	456.5	232.4	0.1	0.1		
	650	23314.3	12270.7	2.5	1.3		
	670	399.3	216.6	0.1	0.1		
	680	33.6	18.5	0.1	0.1		
	700	1138.6	642.8	0.1	0.1		
	710	976.5	558.0	0.1	0.1		
	730	162.5	95.0	0.1	0.1		
	750	14738.6	8799.2	1.6	0.9		
	770	14506.4	8830.0	1.6	0.9		
	780	8933.6	5487.8	1.0	0.6		
	800	23124.2	14452.6	2.5	1.5		
	820	933.3	592.8	0.1	0.1		
	850	2344.3	1522.2	0.3	0.2		
	870	2332.8	1535.5	0.3	0.2		
	900	16878.6	11321.0	1.8	0.1		
	950	1982.6	1367.3	0.2	0.2		
	1000	23720.4	16759.0	2.5	1.8		
	1040	253.6	182.3	0.1	0.1		
	1150	447.0	334.2	0.1	0.1		
	1200	31382.8	23817.3	3.4	2.5		
	1300	13982.0	10887.6	1.5	1.2		

TABLE 12. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	1330	318.8	250.0	0.1	0.1		
	1440	10347.1	8320.6	1.1	0.9		
	1450	1144.3	918.8	0.1	0.1		
	1530	240.5	195.7	0.1	0.1		
	1600	5490.4	4515.1	0.6	0.5		
	1800	24327.6	20508.7	2.6	2.2		
	1910	1045.9	891.6	0.1	0.1		
TOTAL		935872.5	209264.0			66.2	14.8
6	90	2555.3		5.9			
	100	6235.8		14.4			
	110	8263.3		19.1			
	120	4484.1		10.4			
	130	1128.1		2.6			
	140	292.2		0.7			
	150	474.4		1.1			
	160	158.1		0.4			
	170	282.3		0.7			
	180	173.8		0.4			
	400	16.4	2.5	0.1	0.1		
	440	13.8	3.4	0.1	0.1		
	450	1050.3	283.9	2.4	0.7		
	470	74.4	22.9	0.2	0.1		
	490	53.2	18.1	0.1	0.1		
	500	215.9	77.1	0.5	0.2		
	600	758.1	364.5	1.8	0.8		
	630	601.6	306.3	1.4	0.7		
	720	2054.7	1187.9	4.8	2.7		
	850	175.0	113.6	0.4	0.3		
	900	5758.9	3862.7	13.3	8.9		
	1300	1150.8	896.1	2.7	2.1		
	1780	2838.1	2004.6	5.5	4.6		
	1800	4877.4	4111.8	11.3	9.5		
TOTAL		43230.6	13255.4			3.1	0.9
7	90	1550.0					
	100	3782.6					
	110	5021.7					
	120	2720.0					
	130	648.4					
	180	7.0					
	300	361.1					
	320	35.5					
	350	253.4					

TABLE 12. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
7 (Cont.)	380	1.0	0.1				
	410	115.7	21.0				
	450	109.4	29.6				
	580	11618.2	5344.4				
TOTAL		26237.2	5395.1			1.9	0.4
8	90	1665.7		5.9			
	100	4423.0		15.7			
	110	5382.5		19.1			
	120	2923.1		10.4			
	130	696.8		2.5			
	140	559.2		2.0			
	170	239.9		0.9			
	250	105.7		0.4			
	320	1289.0		4.6			
	350	1347.5		4.8			
	360	2376.6	84.9	8.4	0.3		
	400	1052.7	164.5	3.7	0.6		
	500	695.2	248.3	2.5	0.9		
	600	1448.6	696.4	5.1	2.5		
	650	45.6	24.0	0.2	0.1		
	660	1453.2	776.7	5.2	2.8		
	700	806.7	455.4	2.9	1.6		
	870	609.3	401.0	2.2	1.4		
	900	167.2	112.1	0.6	0.4		
	1000	892.6	630.6	3.2	2.2		
TOTAL		28180.1	3593.9			2.0	0.3
9	90	917.5		5.9			
	100	2239.0		14.4			
	110	2964.6		19.0			
	120	1610.0		10.3			
	130	383.7		2.5			
	140	69.1		0.4			
	150	80.6		0.5			
	180	1314.3		8.4			
	190	57.0		0.4			
	250	331.0		2.1			
	260	1347.6		8.6			
	280	439.9		2.8			
	350	2477.8		15.9			
	500	1289.7	460.6	8.3	3.0		
TOTAL		15590.9	460.6			1.1	0.1

TABLE 12. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
10	90	342.8		5.9			
	100	836.7		14.4			
	110	1138.2		19.6			
	120	601.6		10.4			
	130	143.4		2.5			
	200	1191.6		20.5			
	270	1085.2		18.7			
	1400	460.7	366.5	7.9	6.3		
TOTAL		5799.3	366.5			0.4	0.1

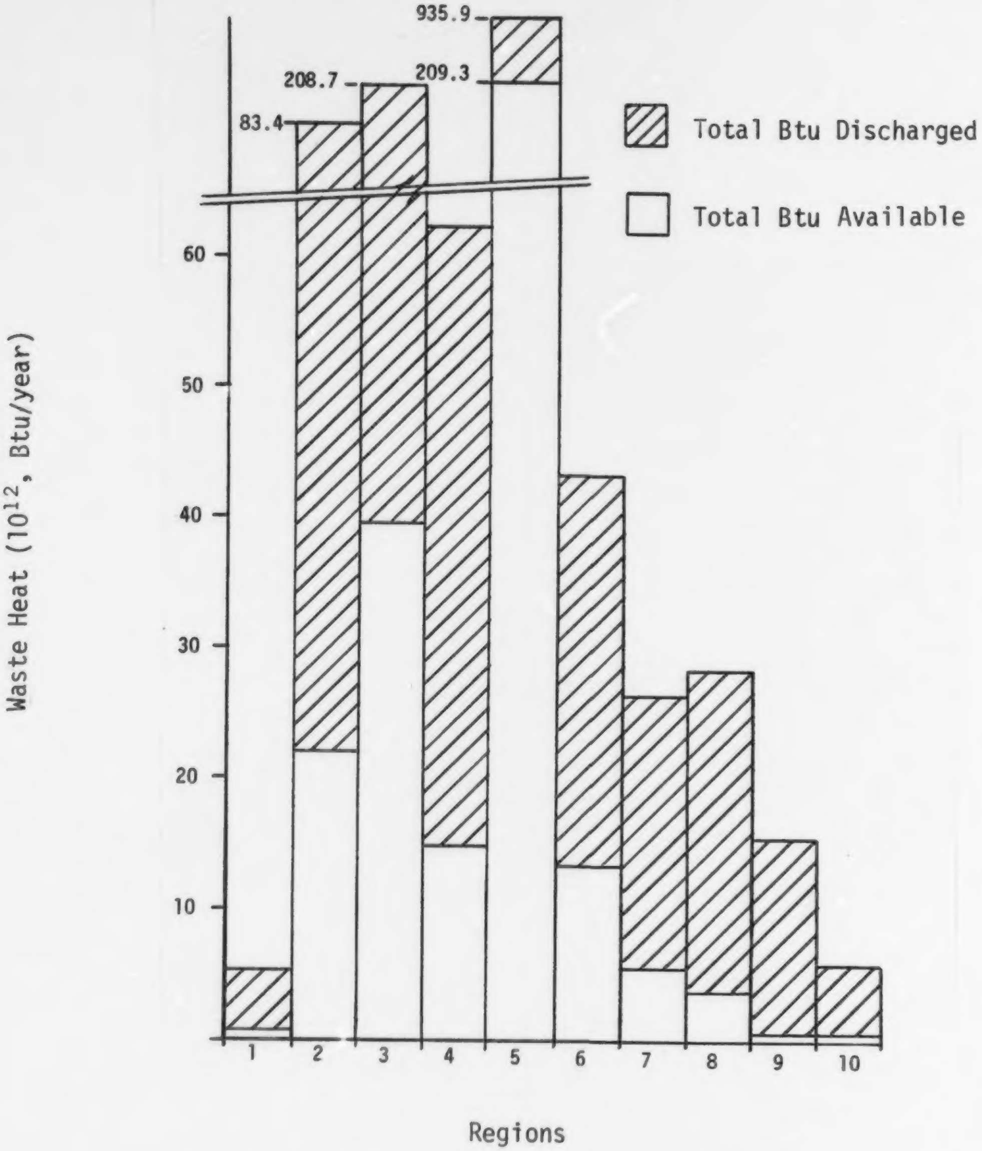

Figure 9. Regional totals for Blast Furnaces and Steel Mills (SIC 3312), (1977).

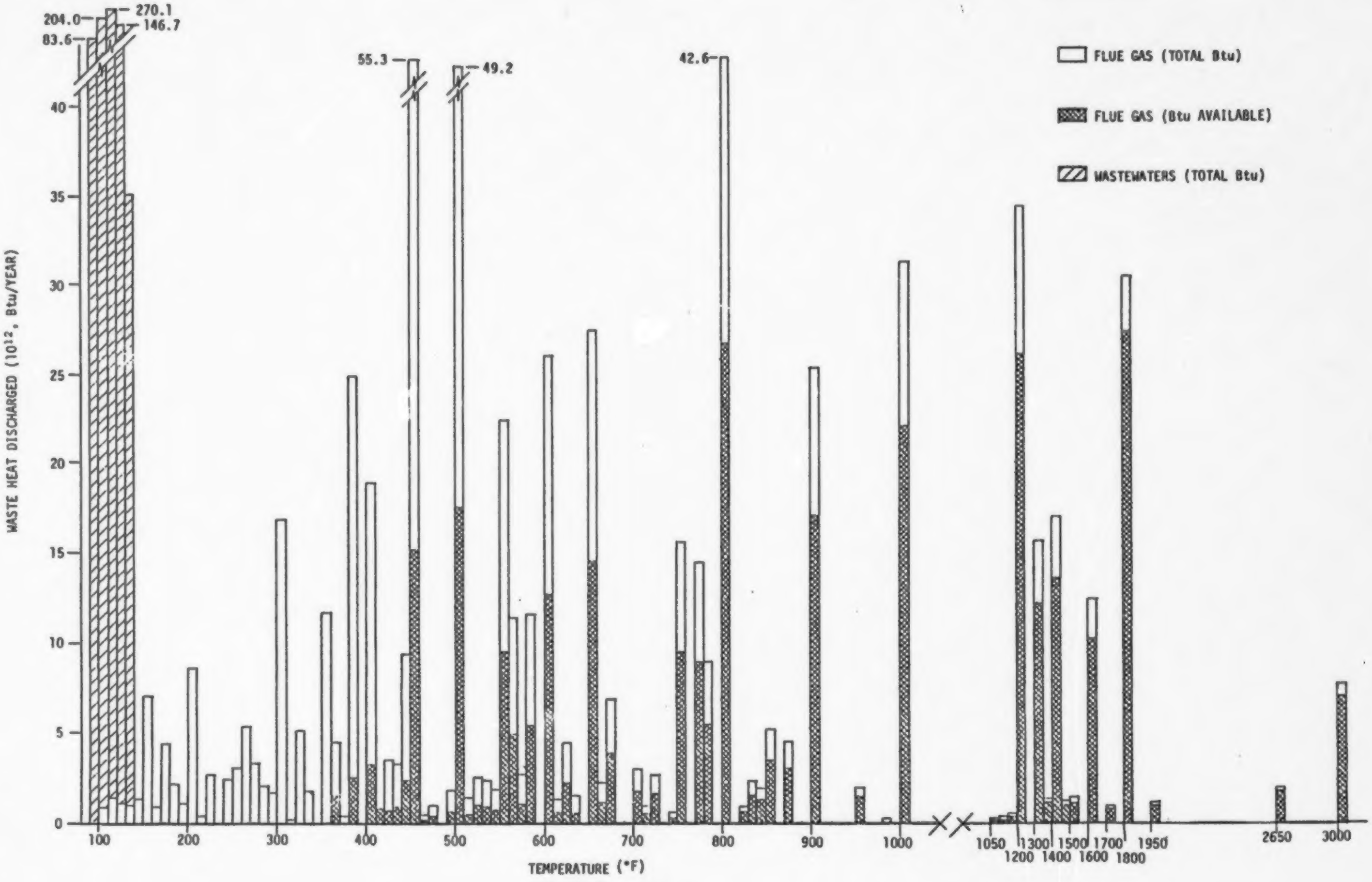

Figure 10. Waste heat temperature profile for Blast Furnaces and Steel Mills (SIC 3312).

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GREY IRON FOUNDRIES (SIC 3321)

General Description

Grey Iron Foundries, SIC 3321, are defined as establishments primarily engaged in manufacturing grey iron castings, including cast iron pressure and soil pipes and fittings. Although not specified in the general description, castings of ductile iron are a primary product of the grey iron foundry industry. The exact size, shape, and composition of castings vary with buyers' needs. Some of the more common applications include the following:

GREY IRON	DUCTILE IRON
Soil Pipe	Gears
Ingot Molds	Turbocharger Housings
Cylinder Blocks	Pressure Valves
Brake Drums	
Range Tops	

The basic foundry process is essentially the same regardless of the method of melting, molding, or finishing.

Geographical Distribution

The grey iron foundry industry was made up of 971 establishments in 1972. Casing production is concentrated in the more industrialized areas. More than 80% of the total tonnage shipped in the U.S. comes from three regions; the Middle Atlantic, East North Central, and East South Central. More than 40% comes from Michigan, Pennsylvania, and Ohio alone.

Shipments of grey and ductile iron castings for 1973 totaled an estimated 13.9 million tons.

Energy Consumption

The melting process involves the reduction of iron scrap and pig iron to a molten state. Grey iron foundries employ basically two types of equipment for the majority of melting operations, the cupola and the electric furnace.

The cupola is a cylindrically shaped furnace that is fueled by coke, a combination of metallic charge, and flux, commonly limestone. The coke charge serves both a thermal and chemical capacity, in that it contributes heat and carbon to the melt. Generally 25% to 35% of the energy in coke is consumed in melting. Combustion is assisted by a blast of air blown upward through the melting zone. In most cupolas, the air is preheated using a gas-fired or sometimes oilfired flame. Such "hot blast" units help to optimize combustion and reduce coke consumption.

Cupola melting is the predominant furnace operation, accounting for 84% of the total metal melted in grey iron foundries. Electric melting accounts for 16%.

In the past, there has been a slight trend towards electric melting, despite the higher energy costs, because of better quality control, less air pollution, and a more amiable working environment. However, with the present oil shortage and conversion to coal as a primary fuel source for electric power generation, it has become more economical to fire coke (converted from coal with 95% efficiency) for direct application of the thermal energy, rather than converting coal energy to electricity (which with best conventional thermal efficiencies might only reach 40%).

In grey iron production, the tonnage of metal melted in a given year is substantially greater than the shipments for that year because the casting yield is considerably less than 100%. The sprue, which feeds molten metal to the casting cavity, is all scrap and must be removed together with gates, rises, fins, and any defective castings. The average yields in grey and ductile iron productions are 60% and 55% respectively, with an overall average yield range from 50% to 75%. For this report, tonnages will represent metal melted and not shipped, unless specifically stated otherwise.

Some ferrous castings are heat treated; either to relieve internal stresses produced in cooling, or to alter the mechanical properties of the casting. Gas is the most common energy source for heat treating.

Data on the energy consumption of the grey iron foundry industry was very inconsistant. Since no reasonable assumptions could be made on total energy or heat rate requirements, it was necessary to sum up process energy consumptions for the melting and heat treating operations. These two processes have been estimated to consume anywhere from 75% to 90% of the total foundry energy consumption.

There are a number of other energy requirements, other than melting and heat treating, which taken together add up to a considerable energy demand. This includes mold and core preparation (drying, baking, preheating, etc.), ladle drying, preheating make-up air, space heating, and many others. These applications are quite varied in themselves and operating practices vary so much from one foundry to another that no reliable estimate of annual energy consumption for these processes was possible. The best that can be said is that the estimates have been made that figure in the range from 10% to no more than 25% of the industry's total requirement. Makeup air and space heating probably accounting for the largest part of it.

The annual energy consumption by melting and heat treating operation are presented in Table 13. For the annual consumption data, it was assumed that 17% of the total tons shipped by grey iron foundries were heat treated at a heat rate of 2 million Btu per ton.

TABLE 13. ANNUAL ENERGY CONSUMPTION FOR MELTING AND HEAT TREATING

	Btu/Melted	Total Tons Melted	% Melted in Furnace Type	Btu Annually
Cupola	$3,886 \times 10^3$	23.4×10^6	.84	76.4×10^{12}
Electric	$2,047 \times 10^3$	23.4×10^6	.16	7.7×10^{12}
Heat Treatment	Btu / Ton Shipped	Tons Shipped	% Treated	Btu Consumed Annually
	2×10^6	13.86×10^6	.17	4.7×10^{12}
			Total Consumption	88.8×10^{12}

Point Sources of Waste Heat

The major sources of waste heat in the grey iron foundry industry are: stack gases from melting furnaces and heat treating ovens; non-contact cooling waters for furnaces and associated equipment; and process waters, used for off-gas washing and cooling.

Non-contact cooling waters are those waters, used for cooling purposes, which do not come into contact with the product or by-products and are discharged or recycled without degradation of the initial water quality, other than an elevation in temperature. Cupola cooling requires an estimated 3,700 gallons/ton of non-contact cooling water. This stream has an average differential pressure of 10°F resulting in waste heat discharges of 3.09×10^5Btu per ton. Electric furnace cooling requirements were estimated at 1,300 gallons/ton with a differential temperature of 36°F. This results in a waste heat discharge of 3.90×10^5Btu per ton.

Process waters for furnace emissions control and quenching are produced in wet or semi-wet exhaust systems only. In 1972, approximately 31% of the total tonnage shipped in SIC 3321 was produced in wet or semi-wet systems. The average flow rates for these process waters were estimated at 3,187 gallons per ton with a differential temperature of 25°F, resulting in a waste heat discharge of 6.65×10^5Btu per ton.

A summation of the stack gases from melting furnaces, heating treating ovens, boilers and other combustion and process offgases are presented in Table 14.

Discussion - Tables and Graphs

Table 14 presents a summation of the waste heat discharged from grey iron foundries according to this point source. This table indicates that almost 66% of the purchased fuels and electricity is discharged as waste heat. Of this, about half is discharged at temperatures greater than 350°F.

Table 15 presents a breakdown of the total waste heat discharged by EPA region and discharge temperature. EPA regions 4 and 5 are the largest dischargers of waste heat from the grey iron industry. Together these two regions account for 70% of the total waste heat discharged by the grey iron industry. A summary of the regional waste heat discharged is presented in Figure 11.

The waste heat temperature profile for the grey iron industry is presented in Figure 12. This indicates that the discharge temperatures of the waste heat streams are quite varied over a large range of temperatures. The most significant discharges being flue gas at 500°F and cooling waters at a temperature of 110°F.

TABLE 14. TOTAL WASTE HEAT DISCHARGED BY GREY IRON FOUNDRIES (SIC 3321)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($x10^9$)	TOTAL Btu AVAILABLE ($x10^9$)	% Btu AVAILABLE	% WASTE① HEAT
	FLUE GASSES					
BL	Process, NEC	100-1950	14842.47	5930.32	39.95	13.32
1	Scrap, Preparation	100-3200	30732.85	17791.90	57.89	27.57
2	Cupola	100-2000	1934.30	841.71	43.51	1.74
3	Furnace, Reverb.	150-800	45.23	21.83	48.26	0.04
5	Furnace, ARC	100	5.13	0.00	0.00	0.00
9	Casting	120-380	18.96	0.43	2.27	0.02
41	Combustion, NEC	600	205.45	98.77	48.07	0.18
60	Combustion, Coal	100	0.20	0.00	0.00	0.00
70	Combustion, Coal	340-500	152.80	28.13	18.41	0.14
80	Combustion, Coal	200-360	1950.46	69.60	3.57	1.75
99	Combustion, NEC	100-480	26.56	2.75	10.35	0.02
00	Combustion, NEC	110-1500	1356.81	493.80	36.39	1.22
	FLUE TOTALS	100-3200	51271.22	25279.24	49.30	45.99
	WASTEWATER					
	Gas Scrubbers	105	10812.90			9.70
	N-C Cooling	90	5024.00			4.51
	N-C Cooling	116	6341.40			5.69
	TOTAL WASTEWATER	90-116	22178.30			19.89
	TOTAL	90-3200	73449.52	25279.24	34.40	65.90

① Based on purchased fuel & electricity

② NEDS data, EPA/2-76-005 OAQPS guidelines

TABLE 15. REGIONAL WASTE HEAT DISCHARGED BY GREY IRON (SIC 3321)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	90	118.0		6.9			
	110	258.0		15.0			
	120	148.8		8.6			
	270	5.6		0.3			
	300	19.4		1.1			
	350	97.1		5.6			
	400	359.6	56.2	20.9	3.3		
	420	15.5	3.2	0.9	0.2		
	1000	71.1	50.3	4.1	2.9		
	1200	131.1	99.5	7.6	5.8		
	1300	52.6	41.0	3.1	2.4		
	1400	37.0	29.4	2.1	1.7		
	2000	149.7	128.6	8.7	7.5		
	2300	258.3	226.9	15.0	13.2		
TOTAL		1721.0	635.0			2.3	0.9
2	90	59.0		6.8			
	100	25.6		3.0			
	110	128.4		14.9			
	120	74.3		8.6			
	140	41.3		4.8			
	150	18.3		2.1			
	160	6.9		0.8			
	170	3.0		0.3			
	180	0.1		0.1			
	200	0.9		0.1			
	350	119.7		13.9			
	370	21.2	1.4	2.5	0.2		
	400	2.3	0.4	0.3	0.1		
	450	15.7	4.2	1.8	0.5		
	480	32.1	10.4	3.7	1.2		
	500	17.7	6.3	2.1	0.7		
	610	6.9	3.4	0.8	0.4		
	660	0.7	0.4	0.1	0.1		
	750	6.3	3.7	0.7	0.4		
	800	17.2	10.8	2.0	1.3		
	1000	1.1	0.8	0.1	0.1		
	1200	263.3	199.8	30.6	23.2		
TOTALS		881.4	241.7			1.2	0.3
3	90	564.9		6.8			
	100	10.3		0.1			
	110	1215.7		14.7			
	120	713.0		8.6			
	130	0.5		0.1			
	150	37.6		0.5			

(continued)

TABLE 15. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
3(Cont.)	180	5.1		0.1			
	190	9.0		0.1			
	200	14.8		0.2			
	220	0.1		0.1			
	250	4.4		0.1			
	300	59.5		0.7			
	350	92.2	0.3	1.1	0.1		
	400	196.9	30.8	2.4	0.4		
	450	8.2	2.2	0.1	0.1		
	480	45.0	14.6	0.5	0.2		
	500	404.6	144.5	4.9	1.8		
	520	6.4	2.5	0.1	0.1		
	600	213.0	102.4	2.6	1.2		
	650	10.0	5.3	0.1	0.1		
	750	5.3	3.2	0.1	0.1		
	800	90.5	56.5	1.1	0.7		
	970	26.9	18.7	0.3	0.2		
	1000	106.7	75.4	1.3	0.9		
	1200	275.4	209.0	3.3	2.5		
	1300	75.4	58.7	0.9	0.7		
	1350	378.3	297.9	4.6	3.6		
	1460	137.3	110.4	1.7	1.3		
	1600	1894.0	1557.6	22.9	18.9		
	2000	1454.9	1250.3	17.6	15.1		
	2200	181.7	158.5	2.2	1.9		
	3200	13.3	12.1	0.2	0.1		
TOTALS		8254.6	4110.9			11.2	5.6
4	90	1661.2		6.8			
	100	265.0		1.1			
	110	3579.0		14.6			
	120	2120.8		8,6			
	130	59.9		0.2			
	140	12.4		0.1			
	150	132.5		0.5			
	160	5.0		0.1			
	170	0.7		0.1			
	180	15.5		0.1			
	200	124.2		0.5			
	250	177.8		0.7			
	270	40.1		0.2			
	300	3.2		0.1			
	320	1.6		0.1			
	350	41.5		0.2			

TABLE 15. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOATAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4	400	2406.7	370.6	9.8	1.5		
	480	94.0	30.6	0.4	0.1		
	500	10062.4	3593.7	41.0	14.6		
	600	7.7	3.7	0.1	0.1		
	650	7.2	3.8	0.1	0.1		
	670	14.7	8.0	0.1	0.1		
	700	362.1	204.4	1.5	0.8		
	800	927.3	579.6	3.8	2.4		
	850	36.5	23.7	0.1	0.1		
	900	8,8	5.9	0.1	0.1		
	920	192.5	130.6	0.8	0.5		
	950	283.4	195.4	1.2	0.8		
	1000	2.9	2.0	0.1	0.1		
	1050	134.0	96.7	0.5	0.4		
	1110	93.9	69.3	0.4	0.3		
	1200	26.7	20.2	0.1	0.1		
	1230	489.0	374.2	2.0	1.5		
	1300	10.0	7.8	0.1	0.1		
	1400	146.9	116.8	0.6	0.5		
	1500	100.5	81.4	0.4	0.3		
	1550	1.4	1.1	0.1	0.1		
	1700	1.4	1.1	0.1	0.1		
	1800	155.8	131.4	0.6	0.5		
	1950	0.2	0.2	0.1	0.1		
	2000	56.1	48.2	0.2	0.2		
	2400	409.6	361.9	1.7	1.5		
	2500	2.4	2.1	0.1	0.1		
TOTALS		24538.5	6469.9			33.3	8.8
5	90	1868.3		6.8			
	100	195.2		0.7			
	110	4073.6		14.9			
	120	2566.0		9.4			
	130	114.9		0.4			
	140	14.6		0.1			
	150	354.6		1.3			
	160	565.4		2.1			
	170	238.7		0.9			
	180	85.5		0.3			
	200	169.8		0.6			
	220	14.1		0.1			
	240	84.6		0.3			
	250	48.9		0.2			
	260	8.5		0.1			
	280	2.1		0.1			

TABLE 15. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont.)	290	29.3		0.1			
	300	82.5		0.3			
	320	346.9		1.3			
	340	74.0		0.3			
	350	241.3		0.9			
	360	1950.0	69.6	7.1	0.3		
	400	17.4	2.7	0.1	0.1		
	420	314.7	64.8	1.2	0.2		
	450	31.7	8.6	0.1	0.1		
	460	415.0	120.1	1.5	0.4		
	480	53.9	17.5	0.2	0.1		
	490	2.3	0.7	0.1	0.1		
	500	463.4	165.5	1.7	0.6		
	550	367.7	156.5	13.5	0.6		
	600	11.3	5.4	0.1	0.1		
	650	451.4	237.6	1.7	0.9		
	700	8072.3	4557.0	29.6	16.7		
	740	202.0	119.4	0.7	0.4		
	750	32.6	19.5	0.1	0.1		
	800	54.2	33.9	0.2	0.1		
	850	2.6	1.7	0.1	0.1		
	900	0.5	0.4	0.1	0.1		
	930	11.2	7.6	0.1	0.1		
	940	30.4	20.9	0.1	0.1		
	1000	131.5	92.9	0.5	0.3		
	1100	15.0	11.0	0.1	0.1		
	1200	1786.1	1355.5	6.5	4.9		
	1400	0.7	0.5	0.1	0.1		
	1500	22.55	182.6	0.9	0.7		
	1600	91.9	75.6	0.3	0.3		
	1800	1255.1	1058.1	4.6	3.9		
	2000	71.9	61.8	0.3	0.2		
	2500	59.3	52.7	0.2	0.2		
TOTALS		27299.6	8500.0			37.1	11.5
6	90	79.5		6.8			
	110	171.1		14.7			
	120	100.4		8.6			
	150	61.9		5.3			
	160	139.2		12.0			
	750	169.0		14.5			
	930	49.0	33.4	4.2	2.9		

TABLE 15. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6(Cont.)	1000	41.0	29.0	3.5	2.5		
	1070	40.6	29.5	3.5	2.5		
	1100	45.5	33.4	3.9	2.9		
	1500	264.5	214.2	22.8	18.4		
TOTALS		1161.7	339.6			1.6	0.5
7	90	63.5		6.8			
	100	0.4		0.1			
	110	1366.6		14.7			
	120	823.8		8.9			
	140	1.4		0.1			
	150	0.7		0.1			
	160	34.7		0.4			
	200	7.0		0.1			
	250	297.1		3.2			
	260	9.7		0.1			
	350	45.6		0.5			
	370	0.1		0.1			
	380	4.3	0.4	0.1	0.1		
	400	19.9	3.1	0.2	0.1		
	500	29.9	10.7	0.3	0.1		
	700	28.8	16.3	0.3	0.2		
	1000	7.1	5.0	0.1	0.1		
	1100	199.0	146.3	2.1	1.6		
	1150	3.0	2.2	0.1	0.1		
	1200	3531.8	2680.4	38.1	28.9		
	1280	6.9	5.3	0.1	0.1		
	1450	3.6	2.9	0.1	0.1		
	1500	59.9	48.5	0.6	0.5		
	1600	93.9	77.2	1.0	0.8		
	1930	74.5	63.6	0.8	0.7		
	2000	1979.5	1701.1	21.3	18.3		
	2800	15.2	13.7	0.2	0.1		
TOTALS		9279.1	4776.8			12.6	6.5
8	90	0.5		6.6			
	110	1.1		14.5			
	120	6.0		78.9			
		7.6	0.0		0.1		0.0
9	90	6.8		6.9			
	110	14.6		14.8			
	120	8.5		8.6			
	480	62.0	20.2	62.8	20.5		
	500	6.8	2.4	6.9	2.4		
TOTALS		98.7	22.6			0.1	0.1

TABLE 15. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
10	90	31.0		6.9			
	110	66.5		14.7			
	120	39.0		8.6			
	150	1.5		0.3			
	200	2.8		0.6			
	250	0.7		0.2			
	400	32.9	5.1	7.3	1.1		
	500	33.0	11.8	7.3	2.6		
	800	18.9	11.8	4.2	2.6		
	880	46.9	31.1	10.4	6.9		
	900	146.0	98.0	32.3	21.7		
	1500	30.5	24.7	6.7	5.5		
TOTALS		451.9	182.5			0.6	0.2

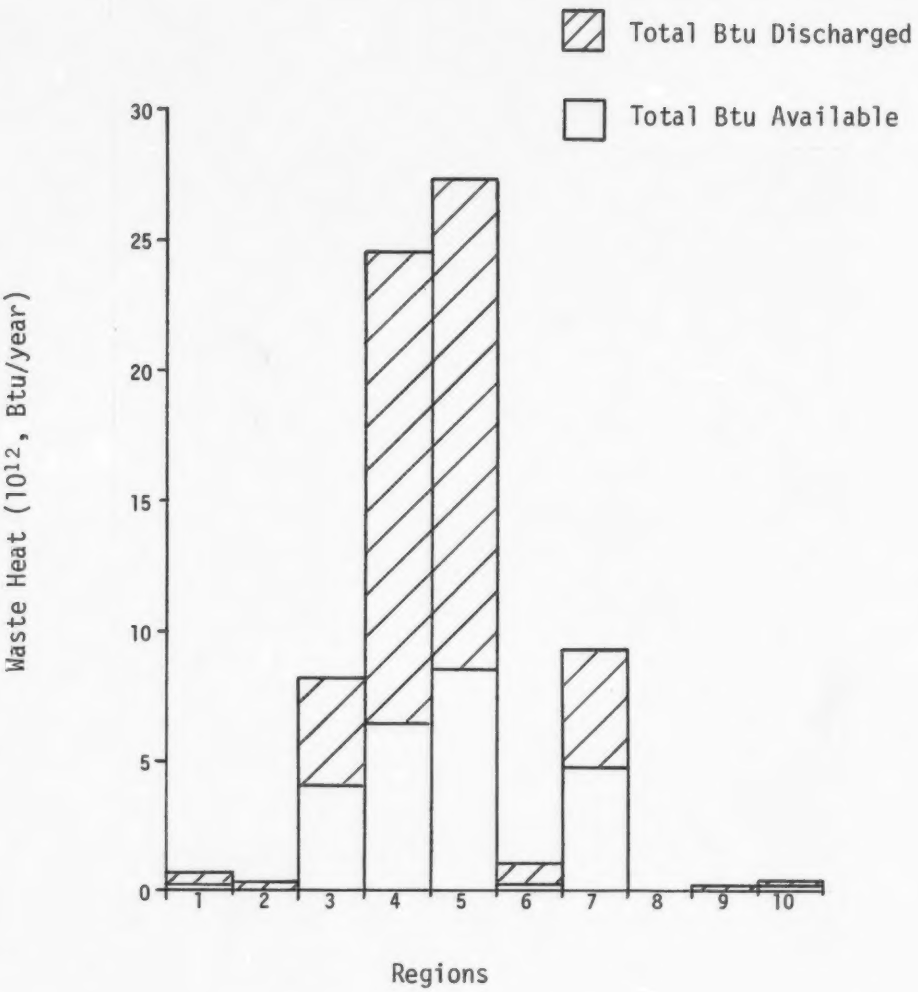

Figure 11. Regional totals for Grey Iron (SIC 3321), (1977).

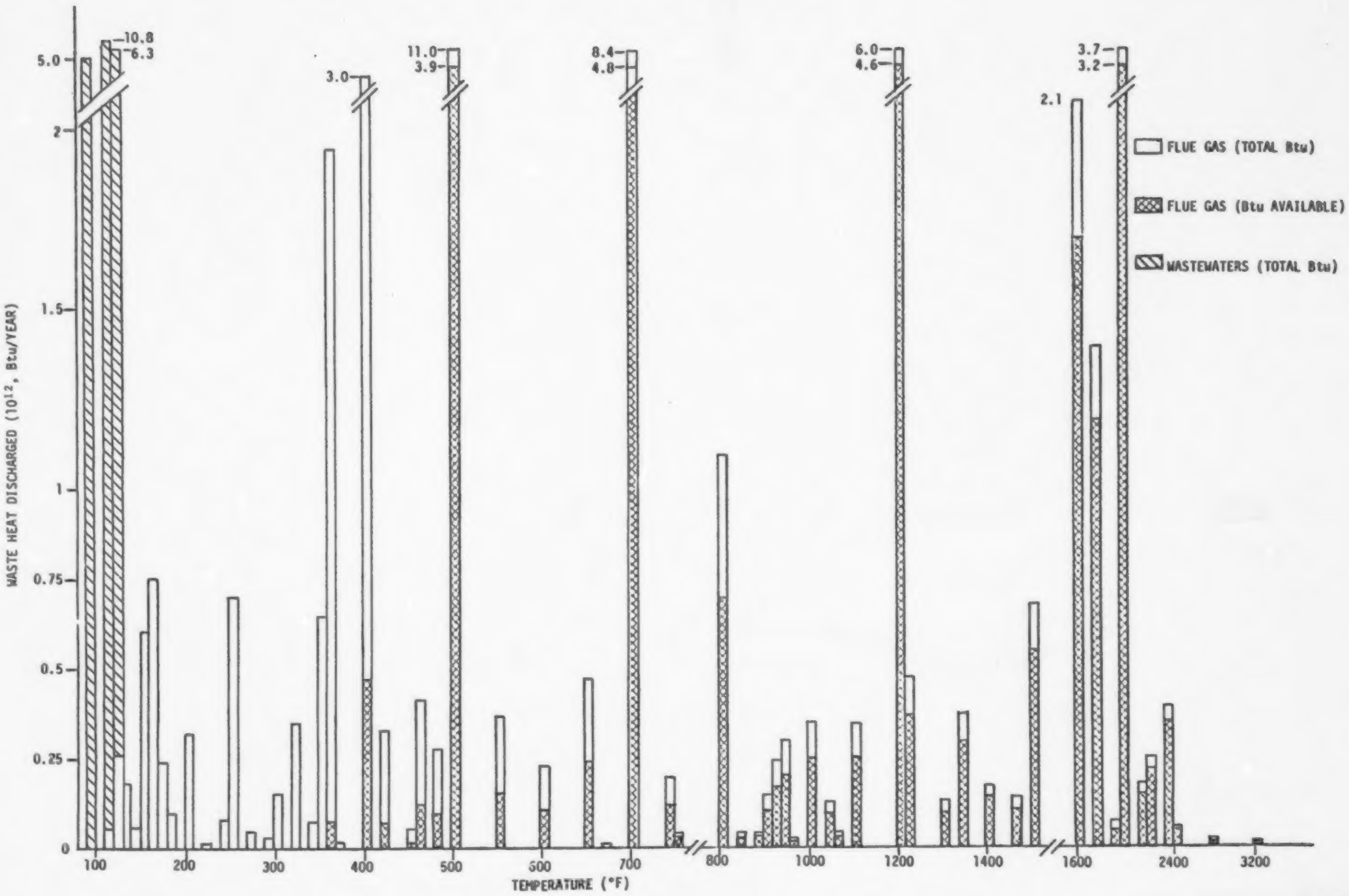

Figure 12. Waste heat temperature profile for Grey Iron (SIC 3321).

COPPER SMELTING (SIC 3331)

General Description

The primary copper industry consists of those establishments engaged in the manufacturing of blister, anode, fire-refined, and cathode copper from copper ores and their intermediate benefits.

The production sequence may be divided into four major segments; mining, beneficiation, smelting, and refining. This report will limit the discussion to the smelting and refining operations as included in SIC 3331. Operations such as the mining and beneficiation of copper ore, as well as the rolling, drawing and extruding of copper, are classified under other SICs and are not a subject of this report.

The primary copper smelting facilities produce copper by pyrometallurgical means. The two conventional smelting schemes used are: roasting - smelting - converting, or smelting and converting.

Roasting - Smelting - Converting

The roasting - smelting - converting processes are generally utilized by facilities which produce a variety of copper concentrates. Seven of the 15 currently operating smelters use roasters as the first pyrometallurgical operation. Roasting reduces, to a controlled degree, the content of sulfur, as well as other impurities contained in the feed. Two different types of roasters are used at these seven domestic facilities; four smelters employ multiple-hearth roasters, while the more modern fluid-bed roaster is used by the other three plants.

The copper calcine is then subjected to the smelting step in either a reverberatory furnace (reverb) or an electric furnace. The main objective of smelting is to collect virtually all of the copper in a molten copper-iron-sulfide material called matte, suitable for subsequent treatment in converters. Heat is supplied to the charge by the burning of powdered coal, oil, or gas. Electrical energy is used where electrical furnaces are utilized.

Of the seven domestic smelters which practice the roasting-smelting converting process, six use reverbs, while an electric furnace is used by only one smelter.

The matte produced in the reverberatory furnace is then charged to a converter where it is converted to a relatively impure form of copper called blister copper. The conversion process is an oxidation process involving the blowing of thin streams of air through the molten material. All seven smelters employ the conventional converter as the converting-step equipment.

Normally, the blister copper will be transferred, while still molten, to a refining furnace. Some, however, may be cast into pigs prior to subsequent refining.

Smelting and Converting

The remaining eight domestic smelters practice the pyrometallurgical sequence of smelting and converting. All eight smelters employ reverbs. One sometimes uses an electric furnace in a new smelter configuration operating in parallel to its older conventional operation.

The process of smelting and converting for this scheme is essentially the same as that described for the roasting-smelting-converting processing scheme, with the end product again being blister copper.

Fire-Refining, and Anode Copper Casting

Fire-refining is a pyrometallurgical operation wherein blister coppper is further refined as either fire-refined copper or anode copper. Fire-refined copper, as a final product, constitutes only a relatively minor percentage of the total production of refined copper. Most primary copper is further purified by electrolytic refining.

Anode furnace refining is used to produce electrodes for subsequent electrolytic refining. Refining furnaces are fueled by coal, natural gas or oil. After reduction, if electrolytic refining is to follow, the refined copper is cast into anodes. If fire-refined copper is the desired end product, casting into various "refined" shapes, such as wirebar, billets, cakes, and ingots, is performed.

Electrolytic Refining

There are 11 known primary electrolytic copper refinery operations in the United States. In this process, copper is separated from impurities by electrolytic dissolution at the anode and deposition as the pure metal at the cathode. The purpose of electrolytic refining is to produce a very high purity copper, and, at the same time, to recover the valuable metal and metalloid impurities that are present in the fire-refined copper.

Geographical Distribution

Most of the copper mined in the United States is produced in five western states: Arizona, Utah, New Mexico, Montana and Nevada. There are 27 major mines that account for over 95% of the copper output. A major portion of the mine production is accounted for by producers who are integrated from mining through fabrication.

Energy Consumption

In 1973, the smelting and refining stages of the primary copper industry consumed nearly 76,897 billion Btu of energy to produce 1.83 million tons of copper; this equates to about 42 million Btu per ton.

Smelting consumed more energy than any other stage of copper production. About 68.3 trillion Btu were required to smelt 1.8 million tons in 1973. This represents about 83% of the total energy consumed in SIC 3331. About

78% of this energy was supplied by natural gas for firing reverberatory furnaces and auxiliary equipment. Smelting required about 35 million Btu per ton of copper. Approximately 68% was consumed by reverberatory furnaces, 6% each in roasting, converting and sulfuric acid plants, 5% in anode casting and 9% in shops and miscellaneous.

In 1973, United States refineries produced 1.87 million tons of copper. Energy requirements for refining averaged about 7 million Btu per ton, resulting in a total of 13.1 trillion Btu consumed. Roughly 13.5% was consumed in the electrolysis state, 25% in melting and casting of residual anodes, 40% in cathode melting and casting into basic shapes, and 21.5% in shops and miscellaneous.

Point Sources of Waste Heat

The major sources of waste heat within the industry are: stack gases from smelting and refining furnaces; aircooling of sulfuric acid plant and electrolytic refining equipment; non-contact cooling waters for furnaces and associated components; contact cooling waters for anode and product cooling; and process waters for wet scrubbing of emissions from smelting furnaces prior to the sulfuric acid plant. All combustion and process offgases are incorporated in Table 16 with their corresponding discharges.

When the slag is tapped off the reverberatory furnace it is either water-granulated or dumped. In most cases it is dumped to conserve water. This slag, because of its high temperatures and quantity, represents a significant portion of the waste heat discharged by the copper industry. Unless water-granulated, slag cooling is primarily a radiant heat loss and therefore it was not a subject of this report. However, it should be considered a prime source for future investigations into waste heat recovery.

Non-Contact Cooling Waters

Non-contact cooling waters used in all the smelting operations, except for the sulfuric acid plants, can vary in temperature and amount according to its specific use and the different operating parameters within each plant. For this reason they were summed up and equated to Btu rejected per ton of product. For these operations it was found that about 7 million Btu were rejected by cooling waters for every ton of anode or fire-refined copper produced. Heat rejection figures for the sulfuric acid plant vary according to the size of the plant and the amount of air cooling performed. For this reason non-contact cooling water heat rejection may range anywhere from 75,000 to 1 million Btu per ton of copper produced for those smelters who have sulfuric acid plants. Non-contact cooling waters used for rectifiers, generators, and the cathode melting furnace also reject heat, dependent on the amount of air-cooling, in the range from 500,000 to 2,000,000 Btu per ton of copper produced.

Contact Cooling Waters

Anode and product copper can either be spray cooled or immersed in a bosh tank. It has been estimated that 1,500 to 10,000 gallons, with differential temperature of 20°F to 80°F, are used for contact cooling per ton of product. This represents a heat rejection range from 1 to 3 million Btu per ton of copper product.

Process Waters

Process waters used in the sulfuric acid plant for furnace gas scrubbing is highly dependent on the size of the plant. Not all copper smelters produce sulfur from their furnace emissions, but for those that do, it has been estimated that heat rejection by these process waters ranged from 100,000 to 5,000,000 Btu per ton of copper produced.

Discussion - Tables and Graphs

The total annual waste heat discharged by the Primary Copper Industry (SIC 3331) is presented in Table 16. This indicates that more than 95% of the industry's purchased fuels and electric energy was discharged as waste heat in 1977. Flue gases account for only 72% of this total, while wastewaters accounted for about 28%. Only 18% of the total waste heat discharged by the primary copper industry was discharged at temperatures over 350°F.

Table 17 presents a breakdown of the total waste heat discharged according to EPA region and temperature. EPA region 9 contributed the greatest quantity of waste heat, alone accounting for 71% of the total industry discharge. EPA regions 9, 6, and 4, together, account for 94% of the industry waste heat discharged.

The waste heat temperature profile for the Primary Copper Industry (SIC 3331) is presented in Figure 14. This figure indicates that wastewater discharged at 100°F contributed more waste heat than any other discharge temperature.

TABLE 16. TOTAL WASTE HEAT DISCHARGED BY PRIMARY COPPER (SIC 3331)

② IPR #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($x10^9$)	TOTAL Btu AVAILABLE ($x10^9$)	% Btu AVAILABLE	% WASTE① HEAT
	FLUE GASSES					
BL	Process, NEC	130-950	19290.74	3319.60	17.20	24.02
1	Roaster	200-530	23482.55	4368.60	18.60	29.24
6	Refining	180-1000	4115.94	2516.30	61.13	5.12
20	Combustion, Coal	300	294.00	0.00	0.00	0.37
50	Combustion, Coal	210	57.82	0.00	0.00	0.07
70	Combustion, Coal	230	256.60	0.00	0.00	0.32
00	Combustion, NEC	350-1000	7602.53	4064.41	53.46	9.47
	FLUE TOTAL	130-1000	55100.18	14268.91	25.90	68.60
	WASTEWATER					
	N-C Cooling in smelting	100	13,440			16.74
	N-C Cooling in acid plants	INSUFFICIENT DATA,				
	N-C Cooling in refining	100	2400			2.98
	Contact cooling for anodes & copper product	120	5500			6.85
	Acid Plant Gas scru.	INSUFFICIENT DATA,				
	TOTAL WASTEWATERS (EXCL. ACID PLANTS)		21340.00			26.57
	TOTAL (EXCL. ACID PLANTS)		76440.18	14268.91	18.60	95.17

① Based on purchased fuel & electricity

② NEDS data, EPA/2-76-005 OAQPS guidelines

TABLE 17. REGIONAL WASTE HEAT DISCHARGED BY PRIMARY COPPER (SIC 3331)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	112.9		20.7			
	120	39.2		7.2			
	130	3.5		0.6			
	150	51.6		9.5			
	360	338.5	12.1	62.0	2.2		
TOTALS		545.6	12.1			0.7	0.1
3	100	92.1		19.9			
	120	33.6		7.3			
	270	62.2		13.4			
	490	203.2	69.4	43.9	15.0		
	600	54.9	26.4	11.9	5.7		
	950	16.9	11.7	3.7	2.5		
TOTALS		462.9	107.5			0.6	0.1
4	100	1189.9		20.7			
	120	413.1		7.2			
	180	53.7		9.4			
	190	20.8		0.4			
	350	2.1		0.1			
	450	0.4	0.1	0.1	0.1		
	500	109.4	39.1	1.9	0.7		
	800	3868.4	2417.7	67.4	42.1		
	1000	84.9	60.0	1.5	1.0		
TOTALS		5742.7	2516.9			7.5	3.3
6	100	2407.3		20.7			
	120	835.9		7.2			
	220	862.7		7.4			
	300	130.9		1.1			
	450	13.0	3.5	0.1	0.1		
	700	7367.9	4159.3	63.4	35.8		
TOTALS		11617.7	4162.8			15.2	5.4
8	100	318.8		20.7			
	120	110.7		7.2			
	200	133.4		8.7			
	210	163.8		10.6			
	230	88.6		5.8			
	300	538.7		35.0			
	330	185.4		12.0			
TOTALS		1539.4	0.0			2.0	0.0

(continued)

TABLE 17. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
9	100	11277.7		20.7			
	120	3915.9		7.2			
	180	137.8		0.3			
	230	256.6		0.5			
	240	1368.9		2.5			
	320	1370.4		2.5			
	330	902.1		1.7			
	360	8684.7	310.2	16.0	0.6		
	390	5171.7	667.3	9.5	1.2		
	400	8096.3	1265.1	14.9	2.3		
	460	1233.9	357.1	2.3	0.7		
	500	2486.3	888.0	4.6	1.6		
	530	9367.4	3746.9	17.2	6.9		
	540	154.8	63.9	0.3	0.1		
TOTALS		54424.5	7298.6			71.2	9.5
10	100	435.2		20.7			
	120	151.1		7.2			
	350	1240.9		59.1			
	800	273.5	171.0	13.0	8.1		
TOTALS		2100.7	171.0			2.7	0.2

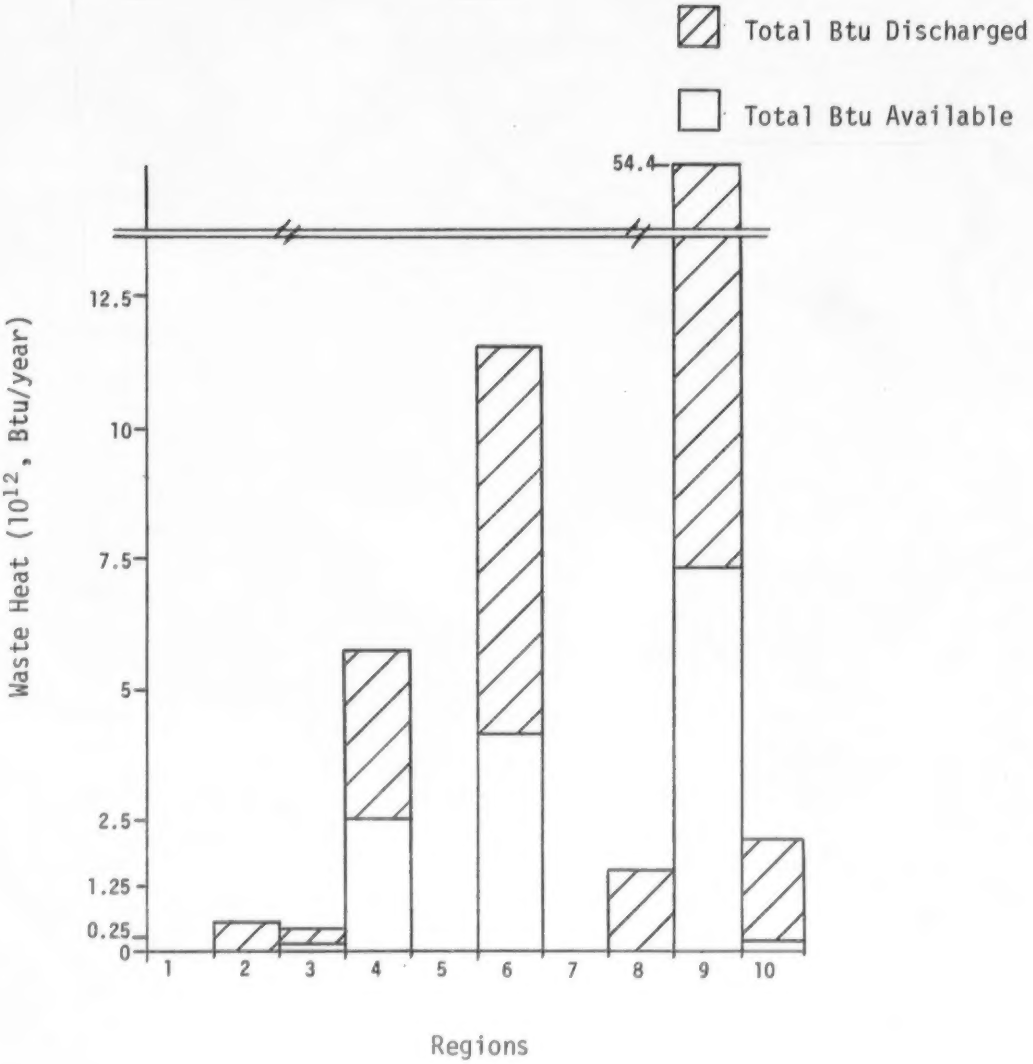

Figure 13. Regional totals for Primary Copper (SIC 3331), (1977).

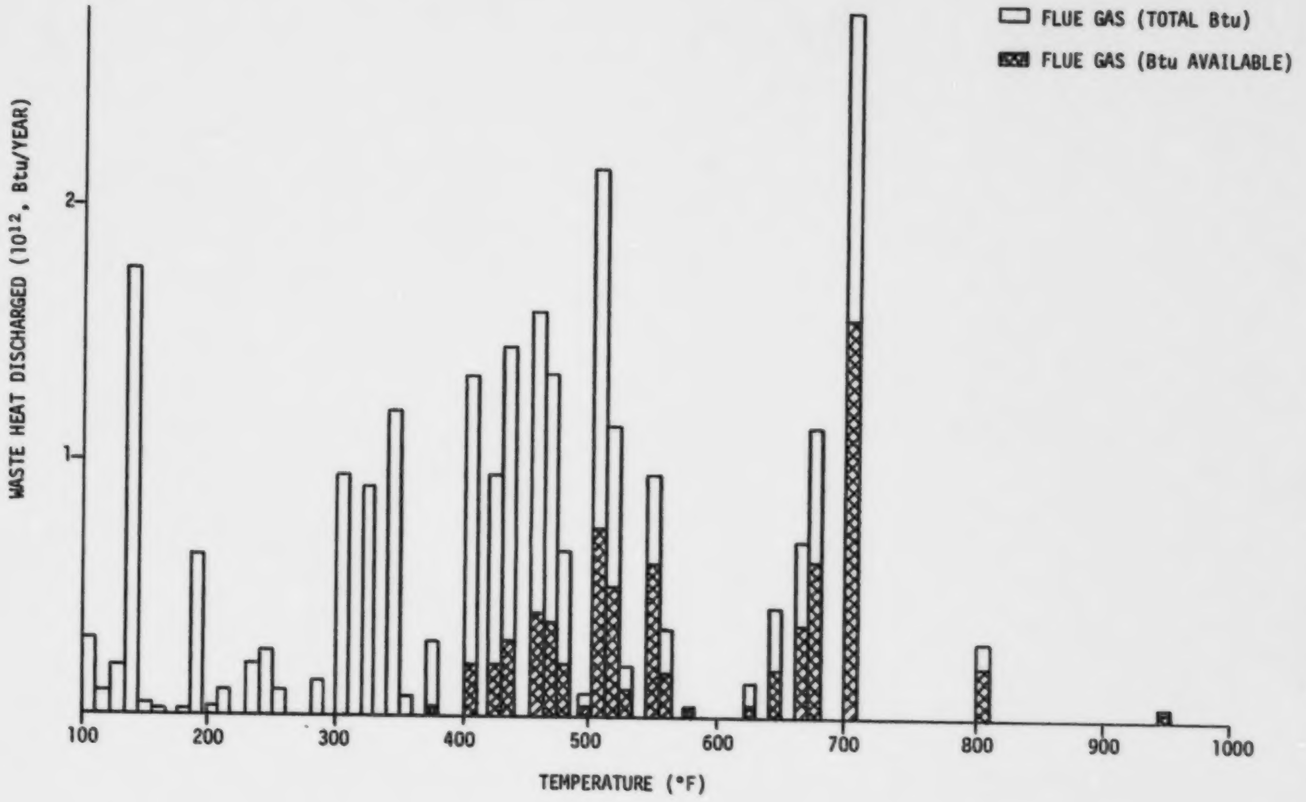

Figure 14. Waste heat temperature profile for Primary Copper (SIC 3331).

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PRIMARY ALUMINUM SMELTING (SIC 3334)

General Description

The primary aluminum process is defined as the reduction of purified aluminum oxide (alumina) to produce aluminum metal. There are 31 aluminum reduction plants located in the United States with a total annual capacity of about 4,5000,000 metric tons (5,000,000 short tons). All of these plants utilize the conventional Hall-Herault process for the electrolytic reduction of alumina to aluminum.

Geographical Distribution

The siting of these aluminum plants has been governed by two major considerations. The first consideration was the availability of inexpensive electric power, the second was an access to river systems for the transportation of the alumina. Plants in Missouri, Kentucky, Indiana, Ohio, West Virginia, Tennessee, North Carolina and Alabama take advantage of both the low cost electrical power and the Mississippi-Ohio River transport system. The plants in New York have access to the St. Lawrence for transportation and have less cost hydroelectric power. Plants in Washington, Oregon and Western Montana make use of low cost hydroelectric power.

Aluminia-Energy Consumption

The most energy intensive step in the production of aluminum is the electrolytic reduction of the alumina to aluminum. The energy consumed in this process is primary electrical in nature and generally ranges from 12,000 to 20,000 Kwh/short ton. Thermal energy is also required for anode baking and casting. A summary of the power consumption for the BayerAlumina, Hall-Herault Process is provided in Table 18.

TABLE 18. POWER CONSUMPTION FOR BAYER ALUMINA, HALL-HERAULT (AVERAGE REQUIREMENTS)

	Kwh/Ton[1]	10^6 Btus/Ton[1]	10^6 Btus/Ton[1]
Bayer Process			
Power	552.5	1.78	
Fuel - Steam Generation		13.93	
Lime Calcination		.60	
Alumina Calcination		7.60	
		23.91	23.91
Hall-Heroult			
Power	15,600	53.24	
Fuel - Anode Baking		2.60	
Casting		4.00[2]	
		59.84	59.84
			83.75

[1] Values are for short tons of Aluminum, assuming 1.9 tons of Alumina per ton of Aluminum [2] Casting of a mix of slabs, extrusion billets, and SOWS

The average electrical requirement for aluminum reduction has been reported at 15,600 Kwh/short ton of aluminum produced. If this value is converted to its Btu equivalent (assuming 3,413 Btu/Kwh), the direct electrical consumption of the reduction process becomes 53.2 x 10^6Btu/short ton. In theory, however, the minimum amount of energy required to produce aluminum for alumina in the cell is only about 35% of this value. In comparison with the total energy consumption for the smelting of alumina to aluminum, the electrolytic reduction process accounts for about 90% of the total energy consumed.

Point Sources of Waste Heat

The major sources of waste heat from aluminum smelting consists of: the offgases from the electrolytic reduction cells; flue gas from anode furnaces, stack gases from degassing operations; and from cooling waters for casting and equipment cooling.

Flue Gases

The flue gases discharged to the atmosphere from aluminum smelting plants consist primarily of the byproducts of coal conbustion used in the anode baking furnaces and from the discharge of pot gas from the electrolytic reduction cells. A minor source of waste heat is discharged by degassing operations but the quantity and nature of this stream is quite variable depending upon the specifications of the alloy being cast.

Contact Cooling And Process Waters

The process waters discharged from Aluminum smelting consists primarily of effluents from wet scrubbing operations required to reduce the levels of atmospheric pollutants discharged to the environment. The majority of these process waters result from the wet scrubbing of the fumes and dust from the electrolytic cell. It should be noted, however, that the option to utilize dry scrubbing and electrolytic precipitators does exist, although the majority do use wet scrubbing. Wet scrubbing of flue gases is also used on some anode baking furnaces and on offgases from degassing operations.

It has been estimated that an annual waste heat discharge of 3.28 x 10^{12} Btu results from the discharge of these process wastewaters. These streams are generally discharged with differential temperatures of 15°F.

Non-Contact Cooling Waters

Non-contact cooling waters are used for aluminum casting, rectifier cooling, and miscellaneous equipment cooling. The quantitites utilized can vary considerably depending upon the type of cooling utilized (i.e recycle or once-thru) and the extent of air cooling utilized. Data on non-contact cooling waters is presented in Table 19.

Discussion - Tables and Graphs

Table 19 presents the total annual waste heat discharged by the Primary Aluminum Industry (SIC 3334). This indicates that only 17% of the industry's purchased fuels and electricity was discharged as waste heat to the environment. Of this quantity only 1.57% consisted of wastewater and cooling effluents.

The largest single contributor of waste heat is reported as being the grinder (IPP#1). In reality, the grinder is utilized in the refining and classifying of Bauxite and should be more properly included in the waste heat discharged by Industrial Inorganic Chemicals (Bauxite) and it should therefore be noted that this waste heat is not discharged at the Aluminum smelter but rather at the site of bauxite refining.

A breakdown, by EPA region and discharge temperatures, of the total waste heat discharged by SIC 3334 is presented in Table 20. EPA region 6 is the largest discharge region, accounting for 35% of the total discharges. Data on EPA regional waste heat discharges is summarized in Figure 15.

The waste heat temperature profile for the Primary Aluminum Industry is presented in Figure 16. This data indicates that the most significant discharge temperatures are 300°F, 310°F, and 270°F. These three streams account for about 31% of the total Btu discharged to the environment by the Primary Aluminum Industry. As can be seen from this Figure, and in Table 19, less than 6% of the total waste heat discharged is discharged at temperatures over 350°F. This corresponds to only 1% of the total purchased fuels and electricity for aluminum smelting.

TABLE 19. TOTAL WASTE HEAT DISCHARGED BY PRIMARY ALUMINUM (SIC 3334)

② IPP #	DESCRIPTION	Temperature Range (°F)	Total Btu ($\times 10^9$)	Total Btu Available ($\times 10^9$)	% Btu Available	%Waste Heat[1]
	Flue Gases					
BL	Process, NEC	100-1400	10799.79	1445.06	13.38	3.29
1	Grinder	110-1000	13710.75	1899.27	13.85	4.18
2	Calciner	140	38.62	0.00	0.00	0.01
3	Baking Furnace	150-310	54.32	0.00	0.00	0.02
5	Soderburg Cell	110-350	7743.37	0.00	0.00	2.36
10	Combustion, Coal	170	266.50	0.00	0.00	0.08
20	Combustion, Coal	300	8179.40	0.00	0.00	2.49
30	Combustion, Coal	310	7490.00	0.00	0.00	2.28
00	Combustion, NEC	100-500	4928.53	146.09	2.96	1.50
	Total Flue Gases	100-1400	53211.28	3490.42	6.56	16.21
	Wastewater					
	Process Wastewaters	95	3284.70			
	N-C Cooling	90	1882.10			
	Total Wastewaters		5166.80			1.57
	TOTAL	90-1400	58378.08	3490.42	5.98	17.78

1 Based on Purchased Fuels & Electricity.

2 NEDS data, EPA/2-76-005 OAQPS Guidelines.

TABLE 20. REGIONAL WASTE HEAT DISCHARGED BY PRIMARY ALUMINUM (SIC 3334)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	0.3		0.1			
	120	30.5		0.7			
	130	4.6		0.1			
	200	1272.1		28.7			
	220	1509.3		34.1			
	250	3.0		0.1			
	270	5.6		0.1			
	300	3.2		0.1			
	400	141.4	22.1	3.2	0.5		
	480	524.2	170.4	11.8	3.8		
	490	31.0	10.6	0.7	0.2		
	820	70.3	44.7	1.6	1.0		
	910	47.3	31.9	1.1	0.7		
	920	42.5	28.8	1.9	0.6		
	940	55.8	38.3	1.3	0.9		
	1020	59.9	42.7	1.4	1.0		
	1050	60.2	43.4	1.4	1.0		
	1090	57.2	41.9	1.3	0.9		
	1100	310.0	227.9	7.0	5.1		
	1180	73.8	55.7	1.7	1.3		
	1400	125.6	99.9	2.8	2.3		
TOTALS		4427.8	858.2			8.3	1.6
3	100	45.8		0.4			
	110	13.2		0.1			
	120	9.9		0.1			
	130	2.7		0.1			
	160	7712.9		73.9			
	250	1948.7		18.7			
	320	134.1		1.3			
	350	340.8		3.3			
	680	25.6	14.1	0.2	0.1		
	800	12.7	8.0	0.1	0.1		
	1350	194.5	153.1	1.9	1.5		
TOTALS		10440.8	175.2			19.6	0.3
4	100	461.1		6.8			
	130	14.0		0.2			
	190	3.0		0.1			
	200	8.7		0.1			
	210	170.3		2.5			
	220	3221.5		47.7			
	240	366.3		5.4			
	250	165.2		2.4			

(continued)

TABLE 20. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont)	270	450.6		6.7			
	300	560.6		8.3			
	320	90.0		1.3			
	330	332.8		4.9			
	350	0.7		0.1			
	410	13.1	2.4	0.2	0.1		
	500	91.4	32.6	1.4	0.5		
	600	483.3	232.4	7.2	3.4		
	700	244.6	138.1	3.6	2.0		
	800	66.1	41.3	1.0	0.6		
	1000	11.1	7.8	0.2	0.1		
TOTALS		6754.4	454.6			12.7	0.9
5	110	0.6		0.1			
	130	2.0		0.1			
	140	1.0		0.1			
	150	11.4		0.1			
	160	1.8		0.1			
	170	4.8		0.1			
	220	9.3		0.1			
	270	64.7		0.7			
	280	2.9		0.1			
	300	8179.4		91.5			
	310	49.8		0.6			
	350	2.9		0.1			
	380	87.1	8.7	1.0	0.1		
	390	40.2	5.2	0.4	0.1		
	470	12.7	3.9	0.2	0.1		
	500	8.9	3.2	0.1	0.1		
	700	464.5	262.2	5.2	2.9		
TOTALS		8943.9	283.2			16.8	0.5
6	100	388.9		1.9			
	110	12.2		0.1			
	120	27.0		0.1			
	130	74.0		0.4			
	140	38.6		0.2			
	170	296.3		1.4			
	180	86.8		0.4			
	200	127.1		0.6			
	210	266.6		1.3			
	240	46.2		0.2			

TABLE 20. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6 (Cont)	260	211.4		1.0			
	280	308.2		1.5			
	300	700.3		3.4			
	310	8020.7		39.2			
	320	203.9		1.0			
	350	2726.8		13.3			
	360	83.4	3.0	0.4	0.1		
	370	2440.1	168.3	11.9	0.8		
	390	918.3	118.5	4.5	0.6		
	400	546.3	85.4	2.7	0.4		
	410	221.0	40.2	1.1	0.2		
	420	133.6	27.5	0.7	0.1		
	430	25.8	5.9	0.1	0.1		
	440	214.5	53.6	1.0	0.3		
	450	223.0	60.3	1.1	0.3		
	460	257.1	74.4	1.3	0.4		
	480	157.5	51.2	0.8	0.3		
	510	612.6	228.0	3.0	1.1		
	640	163.4	84.6	0.8	0.4		
	700	41.5	23.4	0.2	0.1		
	860	143.9	94.1	0.7	0.5		
	910	729.4	492.1	3.6	2.4		
TOTALS		20446.5	1610.4			38.4	3.0
10	100	1049.3		47.7			
	120	129.2		5.9			
	150	228.2		10.4			
	180	21.7		1.0			
	300	27.5		1.3			
	350	116.9		5.3			
	360	388.6	13.9	17.7	0.6		
	530	236.9	94.8	10.8	4.3		
TOTALS		2198.4	108.6			4.1	0.2

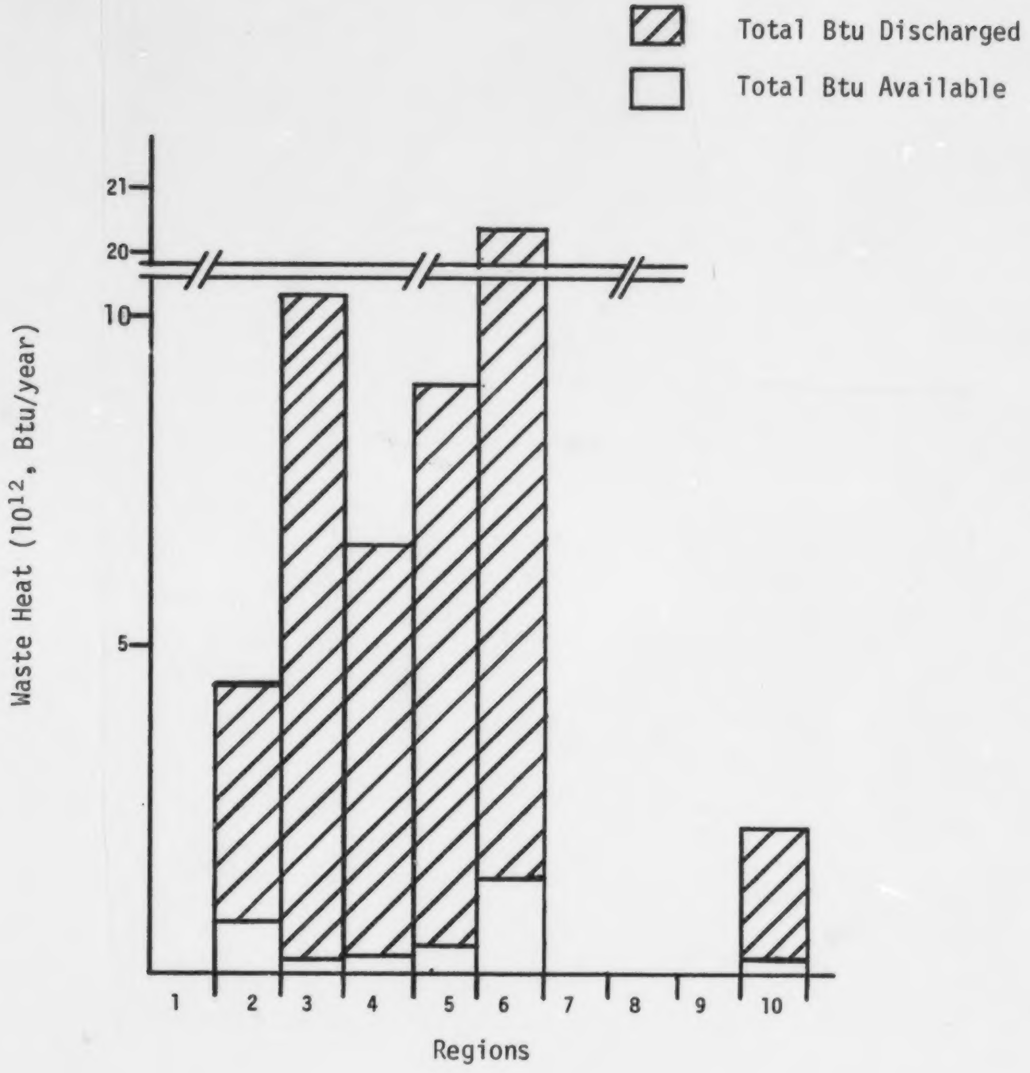

Figure 15. Regional totals for Primary Aluminum (SIC 3334), (1977).

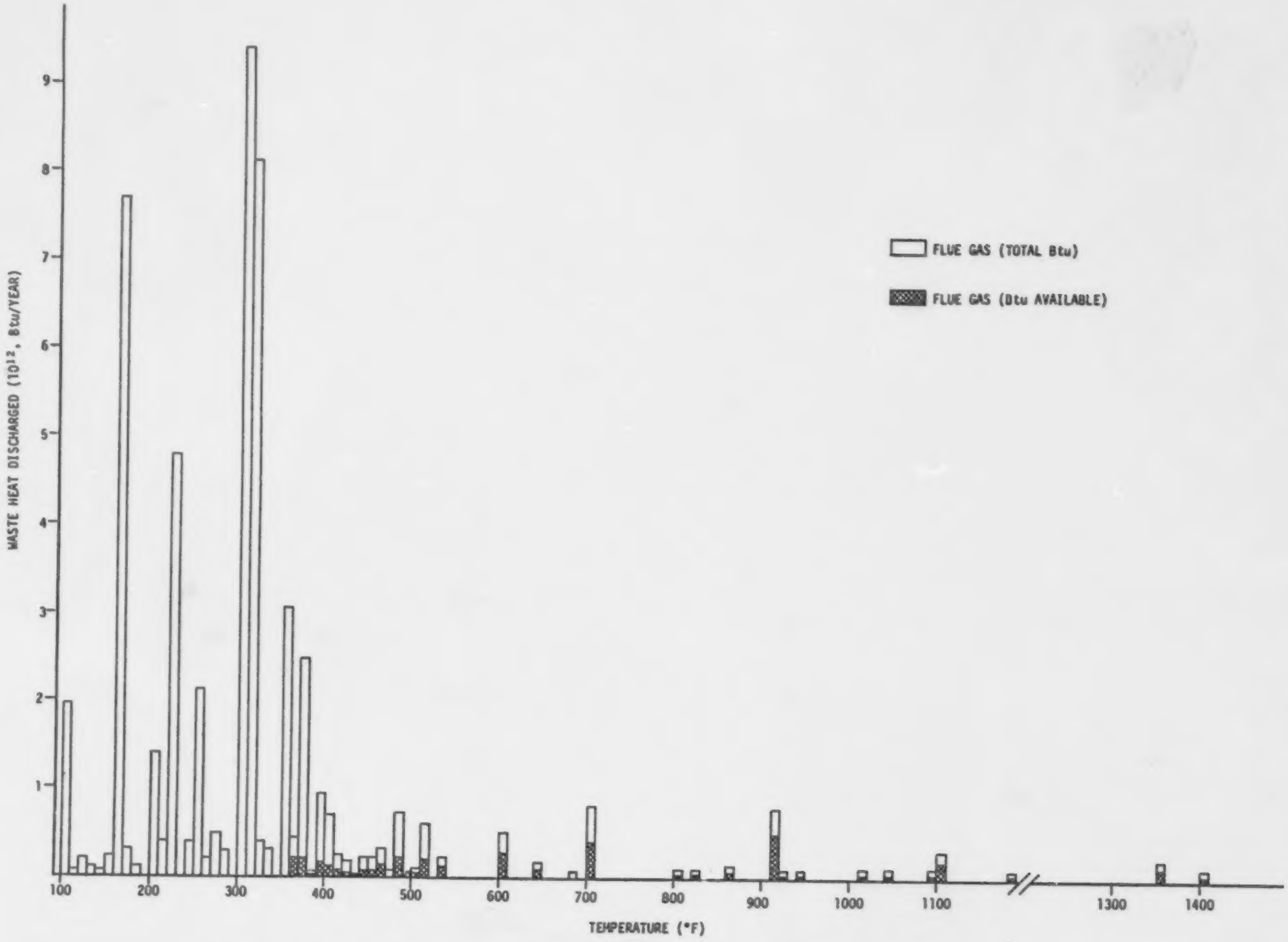

Figure 16. Waste heat temperature profile for Primary Aluminum (SIC 3334).

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SECTION 5

PAPER

PAPER AND ALLIED PRODUCTS (SIC 2611, 2121, 2631)

The pulp, paper, and allied products industry includes the production and sale of pulp, the manufacture of paper and paperboard, and their conversion into end products such as boxes, writing paper, and sanitary tissue. Because the production of pulp is very commonly integrated with the manufacture of paper and paperboard (which are the greatest end uses of pulp), and since, from the point of view of energy consumption and heat rejection, the manufacture of paper and the manufacture of paperboard are nearly identical, it was decided to include the three Standard Industrial Classifications in the same discussion.

General Description

The production of Paper and Allied Products is essentially accomplished in two major operations, pulping and papermaking.

The debarking of pulpwood can be accomplished by several different methods. In the past, two methods were commonly used. On the West Coast, hydraulic debarking, using jets of water, was used to debark the large diameter logs. Elsewhere, with logs of smaller diameter, a technique called friction or drum debarking made use of a rotating drum in which the logs were tumbled and debarked by friction with an actuating mechanism.

The predominant method used in pulping operations is chemical pulping, specifically the Kraft or sulfate process. An estimated 32 million tons of kraft pulp was produced in the United States in 1977, compared with 4.2 millon tons for the groundwood process, the next most widely used pulping process.

There are two main types of papermaking machines; the Fourdrinier and cylinder machine. On both machines, a sheet is formed on a traveling wire or cylinder, dewatered under rollers, dried by heated rolls, and finished by calander rolls.

Geographical Distribution

About 64% of the pulping capacity and 49% of the papermaking capacity now located in the South where, along with the Pacific Northwest, the newer, larger, and integrated mills are located. In the Northeast and North Central regions the mills are often older and smaller, and less likely to be integrated.

Energy Consumption

In 1974, the paper and allied products category was the fifth largest consumer of purchased fuel and electricity among the two-digit Standard Industrial Classifications established by the Bureau of Census. In that year, the United States pulp and paper industry purchased 390.0 billion kilowatt-hours of fuel and electric energy, or 1.33 quads (quadrillion Btu/year) This represents 9.9% of the 13.4 quad total for all industries.

Pulp mills accounted for 0.086 quads, or 25.1 billion Kwh, of purchased energy, while papermills, (except building paper and paperboard mills), consumed 1.08 quads, or 317.5 billion Kwh.

In addition to purchased fuels, the pulp and paper industry makes use of large quantities of residue fuels such as bark, forestry waste, and black liquor, which is formed in certain pulping processes. The burning of these residue fuels provides nearly three-fourths of the energy required for kraft pulping, the dominant pulping process.

The total energy requirements for bleached kraft pulp production is about 27 million Btu/ton of slush pulp and more than half of this is provided by recovered energy from burning bark and black liquor. Fuel is burnt to produce high pressure steam, which is then used to provide electricity and low pressure steam. The net produced energy is about 27 million Btu per ton of product. Digestion, bleaching, concentration of the black liquor, and calcination of wet calcium carbonate, are the main energy consuming steps.

The paper making operation consumes the same amount of energy for a given product irrespective of the type of pulp employed, around 12.7 million Btu per ton of product.

The stream entering the pulpdrying stage may be 65 weight percent water. Because of the evaporation required, papermaking alone uses half as much energy as the entire pulping operation. For one ton of paper product 40.9 million Btu are required, or about 22 million Btu of purchased energy. Most of this purchased energy is applied to papermaking because more than 70% of the energy required for pulpmaking can be recovered from wood wastes.

Point Sources Of Waste Heat

Groundwood Pulping --

This process consumes more energy per pound of pulp produced than any other pulping process because it uses only mechanical energy to effect the pulping of wood.

It has one significant waste heat stream, wastewater from the peroxide bleaching operation, which is discharged with a differential temperature of about 60°F. This corresponds to a waste heat discharge 1.10×10^6Btu per bone dry ton (BDT) of pulp produced.

Kraft Pulping Digestor --

For every pound of bone dry pulp produced, 1.26 pounds of saturated steam at 220°F is flashed off from the digestor. This represents approximately 2.8 x 10^6Btu/BDT of waste heat. This stream is incorporated under Process, NEC in Table 21.

Bleaching --

In a five-stage kraft operation, the wastewater stream from the chlorination stage contains chlorine dioxide, sodium hydroxide, chlorine, lignin, and cellulose. The waste heat content of this effluent was estimated at 400,000 Btu/BDT. In a three-stage bleaching process, the chlorination wastewater stream is discharged with a differential temperature of 7°F, resulting in a waste heat discharge of 1.2 x 10^6Btu/BDT.

Papermaking --

Paper and paperboard manufacture required nearly the same amounts of energy. This energy requirement is not dependent upon the pulping process used. There are two waste heat streams from the papermaking operation. A moist, hot air stream, with a differential temperature of 20°F, yields about 3.10 x 10^6Btu/BDT of waste heat and a hot water stream, saturated at 250°F, which yields about 690,000 Btu/BDT of waste heat.

The multiple-effect evaporator concentrates the black liquor to about 65% solids, enabling it to be burnt in the recovery furnace for reclamation of its inorganic chemicals and to produce high pressure steam. There are two rejected heat streams from the evaporator. Saturated steam at 0.1 atm, with a differential temperature of 25°F, goes to a barometric condenser, discharging approximately 3.30 x 10^6Btu/BDT of waste heat. Foul condensate is discharged to the sewer with a differential temperature of 117°F, discharging about 1.90 x 10^6Btu/BDT of waste heat.

Vapor, containing turpentine, is removed for later processing and sent to storage. This stream is discharged at 220°F yielding approximately 170,000 Btu/BDT of waste heat.

After being concentrated in the evaporator, the black liquor is burnt in the recovery furnace. The flue gas leaves the recovery furnace at approximately 300°F. This results in a waste heat discharge of 5.4 x 10^6Btu/BDT.

Blowdown from the bark, power, and black liquor boilers is discharged at around 320°F. This blowdown contributes 1.13 x 10^5Btu of waste heat per bone dry ton.

The smelt from the recovery furnace is dissolved to produce green liquor. This green liquor is slaked with lime, which effectively replaces carbonate ions in solution with hydroxide ions and causticizes the solution. The calcium carbonate sludge formed is then calcined to regenerate lime. This calcining step produces offgases at 400°F which results in a waste heat discharge of 8.20 x 10^5Btu/BDT. Cooling of hot (650°F) freshly calcines lime, during storage, was reported to account for 40 Btu per pound of paper. This equates to about 84,000 Btu/BDT.

Discussion - Tables and Products

Pulp Mills (SIC 2611)

Table 21 presents the total waste heat discharged by Pulp Mills (SIC 2611) according to its point source. This table indicates that 50% of the purchased fuels and electricity was discharged as waste heat. Most of this waste heat may be considered low-grade (at temperatures below 350°F) as evidenced by the fact that only 5.5% of the waste heat discharged was considered Btu available.

Table 22 presents a regional breakdown of the waste heat discharged by pulp mills according to reported discharge temperatures. This indicates that waste heat discharged by pulp mills were highly concentrated in EPA region 10. This region alone accounted for 63.6% of the total waste heat discharged by pulp mills. A summary of Table 22 is presented in Figure 17.

A waste heat temperature profile for waste heat discharged from pulp mills is presented in Figure 18. This figure indicates that the wastewaters and saturated vapors were the most significant waste heat discharges from pulp mills and that very little of this waste heat energy is discharged at temperatures greater than 350°F.

Paper Mills (SIC 2621)

The total waste heat discharged by paper mills is presented in Table 23. This table presents specific waste heat discharged according to their point source. This industry discharged 40% of their purchased fuel and electric energy as waste heat during 1977. Of this, only 1.7% was discharged as saturated vapors. High-grade waste heat (greater than 350°F) accounts for only 15% of the total waste heat discharged.

A further breakdown of the total waste heat discharged, according to discharge temperature and EPA region, is presented in Table 24. This table indicates that EPA region 4 was the largest discharge region, accounting for 37.7% of the total waste heat discharged by paper mills. This was more than twice the regional discharges of the next largest region. This data is summarized in Figure 19.

The waste heat temperature profile for paper mills is presented in Figure 20. This figure indicates a fairly even distribution of discharge temperatures. The two most significant discharge temperatures were at 350°F and 400°F.

Paperboard Mills (SIC 2631)

The total waste heat discharged by paperboard mills is presented in Table 25. This table presents these waste heat discharges according to the point source. This table indicates that only 19% of this industry's purchased fuels and electric energy was discharged as waste heat in 1977.

Table 26 further differentiates the waste heat discharged by paperboard mills according to EPA regions and by discharge temperature. EPA region 4 was by far the largest waste heat discharge region for paperboard mills. This region alone accounted for 72% of the total waste heat discharged. This data is further summarized in Figure 21.

The waste heat temperature profile for paperboard mills is presented in Figure 22. The most significant discharge temperature was 250°F, with the majority consisting of saturated liquid vapor. This temperature category accounted for almost 17% of the total waste heat discharged.

TABLE 21. TOTAL WASTE HEAT DISCHARGED BY PULP MILLS (SIC 2611)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($x10^9$)	TOTAL Btu AVAILABLE ($x10^9$)	% Btu AVAILABLE	% WASTE HEAT ①
	FLUE GASES					
BL	Process, NEC	100 - 1800	18,886.48	1,804.10	9.55	3.1
1	Recovery Boilers	100 - 470	1,257.33	9.86	0.78	0.2
2	Smelt Dissolving TK	140 - 400	2,433.01	83.60	3.44	0.4
3	Lime Kiln	130 - 430	3,906.37	106.57	2.73	0.6
4	Fluid Bed Calciner	110 - 670	55,341.39	2,176.10	3.93	9.1
5	Oxidation Tower	120 - 570	289.65	0.00	0.00	0.0
10	Combustion, Coal	400 - 570	2,589.55	497.44	19.20	0.4
20	Combustion, Coal	280 - 500	11,462.81	1,604.10	13.99	1.9
30	Combustion, Coal	320 - 360	277.36	3.60	1.29	0.0
40	Combustion, Coal	390 - 600	1,689.87	563.15	33.32	0.3
50	Combustion, Coal	280 - 340	1,146.19	0.00	0.00	0.2
60	Combustion, Coal	340 - 570	4,242.18	992.10	23.38	0.7
70	Combustion, Coal	310 - 600	9,617.33	3,543.52	36.84	1.6
80	Combustion, Coal	280 - 600	14,492.71	1,207.82	8.33	2.4
90	Combustion, Hand Fired	280	56.25	0.00	0.00	0.0
00	Combustion, NEC	120 - 860	94,038.46	23,012.32	24.38	15.6
	Total Flue Gases	100 - 1800	232,512.7	35,602.23	15.31	38.4
	Wastewaters					
	Sat. Wastewater	250	10,474.2			1.7
	Total	100 - 1800	232,512.7	35,602.3	15.31	40.2

① Based On Purchased Fuels & Elec.

② NEDS Data, EPA 450/2-76-005 OAQPS Guidelines

TABLE 22. REGIONAL WASTE HEAT DISCHARGED BY PULP MILLS (SIC 2611)

EPA REGION #	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	120	571.3		14.9			
	160	226.5		5.9			
	170	2.0		0.1			
	180	71.2		1.9			
	200	328.9		8.6			
	220	774.6		20.2			
	260	69.2		1.8			
	300	102.6		2.7			
	320	375.6		9.8			
	420	1,283.5	264.2	33.5	6.9		
	450	25.8	6.9	0.7	0.2		
TOTAL		3,831.2	271.1			7.7	0.5
3	120	27.5		14.9			
	200	15.9		8.6			
	220	24.4		12.7			
	260	3.3		1.8			
	320	0.9		0.5			
	340	113.6		61.5			
TOTAL		184.6				0.4	
4	120	1,024.2		14.9			
	150	15.2		0.2			
	160	56.0		0.8			
	170	119.1		1.7			
	180	227.6		3.3			
	200	589.7		8.6			
	260	124.1		1.8			
	320	451.3		6.6			
	330	3,158.9		46.0			
	350	152.6		2.2			
	500	81.1	28.9	1.2	0.4		
TOTAL		6,868.8	28.9			13.7	0.1
5	120	200.4		14.9			
	180	12.6		0.9			
	200	121.4		9.0			
	220	170.0		12.7			
	260	24.3		1.8			
	320	6.8		0.5			
	350	808.3		60.2			
TOTAL		1,343.8				2.7	

(continued)

TABLE 22. (continued)

EPA REGION #	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6	120	893.1		14.9			
	130	351.3		5.9			
	160	38.1		0.6			
	170	33.0		0.6			
	200	555.6		9.3			
	210	32.6		0.5			
	220	757.8		12.7			
	260	108.3		1.8			
	320	30.5		0.5			
	330	409.0		6.8			
	410	1962.4	356.8	32.8	6.0		
	430	818.0	187.0	13.7	0.2		
TOTAL		5,989.5	543.8			12.0	1.1
10	100	28.3		0.1			
	110	88.1		0.3			
	120	4,829.7		15.2			
	130	12.2		<0.1			
	140	94.8		0.3			
	150	98.1		0.3			
	160	574.0		1.8			
	170	93.9		0.3			
	200	3,101.1		9.8			
	210	110.6		0.3			
	220	4,023.1		12.7			
	250	864.6		2.7			
	260	574.7		1.8			
	270	350.0		1.1			
	280	236.3		0.7			
	290	829.5		2.6			
	300	1,970.0		6.2			
	310	321.1		1.0			
	320	848.9		2,7			
	350	1,220.9		3.8			
	360	1,932.9	69.0	6.1	0.2		
	370	1,621.1	111.7	5.1	0.4		
	380	295.4	29.5	0.9	0.1		
	400	2,255.8	352.5	7.1	1.1		
	420	558.2	114.9	1.8	0.4		
	450	1,812.2	489.8	5.7	1.5		
	500	914.8	326.7	2.9	1.0		
	510	2,137.7	795.4	6.7	2.5		
TOTAL		31,798.0	2,289.5			63.6	4.6

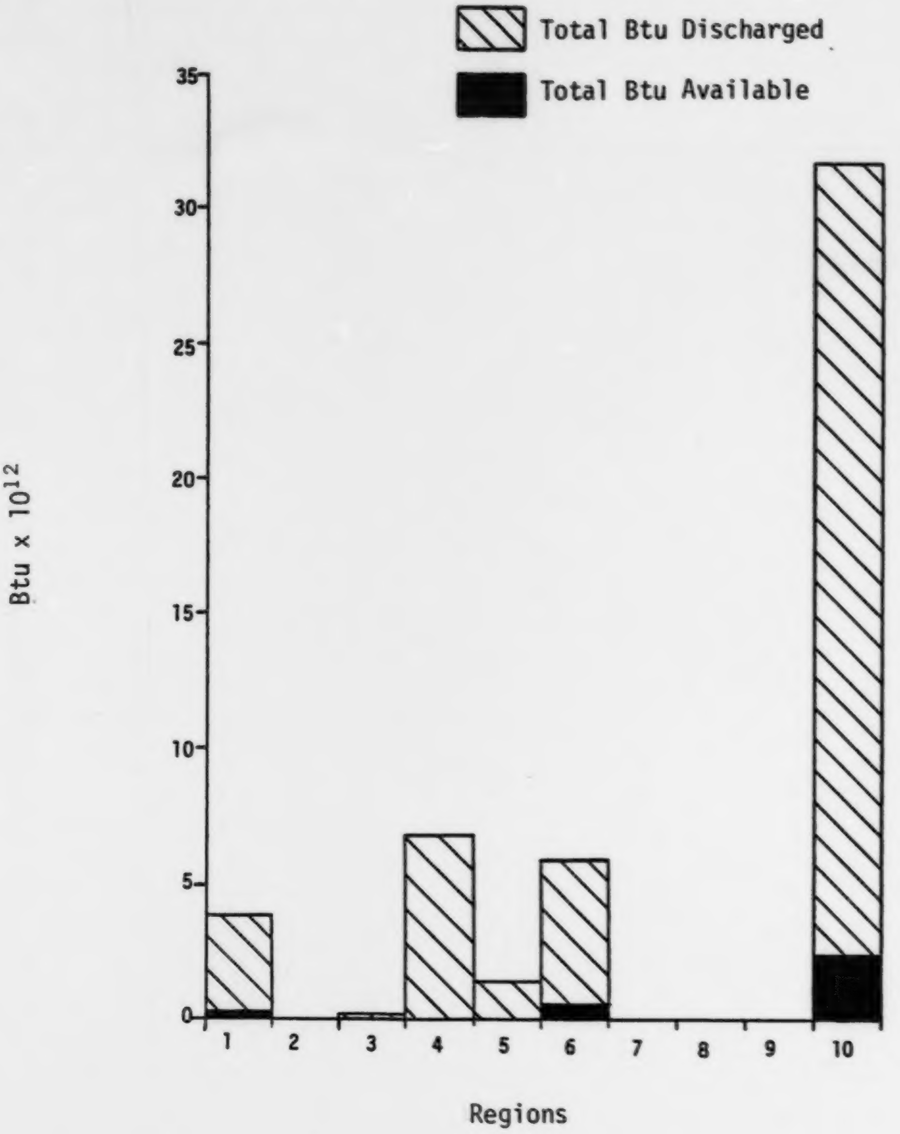

Figure 17. Regional totals for Pulp Mills (2611), (1977).

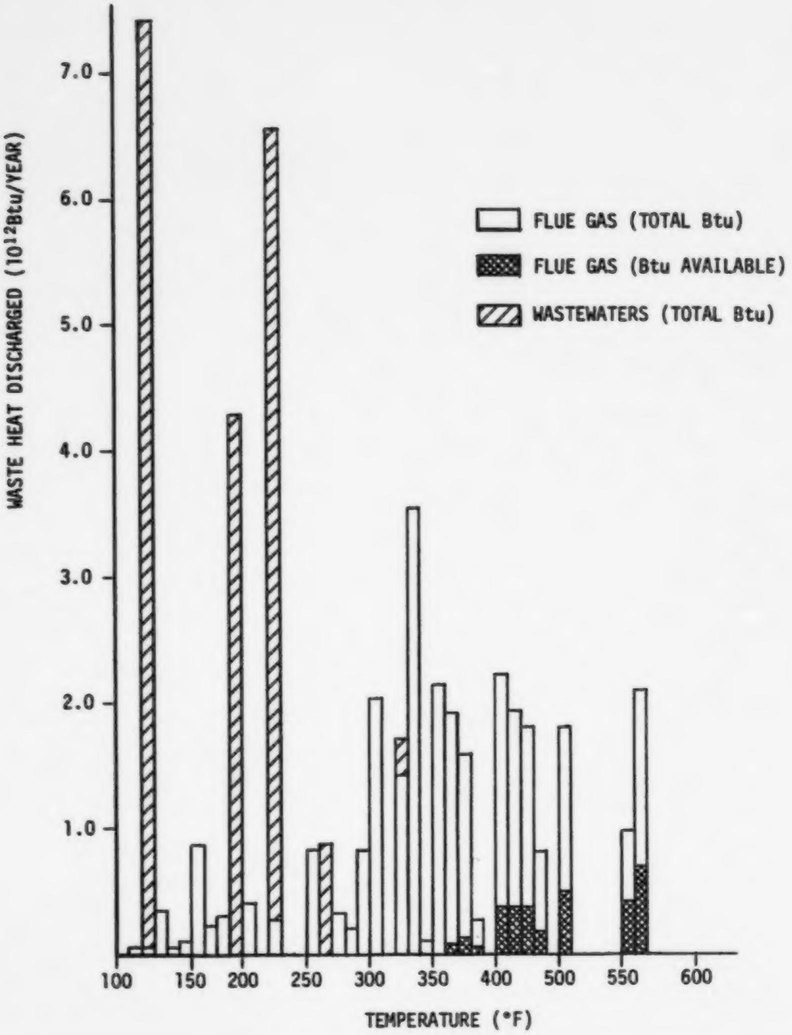

Figure 18. Waste heat temperature profile for Pulp Mills (SIC 2611).

TABLE 23. TOTAL WASTE HEAT DISCHARGED BY PAPER MILLS (EXC. BLDG. PAPER) (SIC 2621)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($\times 10^9$)	TOTAL Btu AVAILABLE ($\times 10^9$)	% Btu AVAILABLE	% WASTE HEAT ①
	FLUE GASES					
BL	Process NEC.	100 - 360	3,787.16	35.13	0.93	4.2
1	Recovery Boilers	130 - 430	1,027.48	186.98	18.20	1.1
2	Smelt Dissolving TK.	140 - 210	251.06	0.00	0.00	0.2
3	Lime Kiln	120 - 200	373.71	0.00	0.00	0.4
4	Fluid Bed Calciner	140 - 370	7,114.21	98.34	1.38	7.9
6	Fiberboard, Drying	160	19.10	0.00	0.00	0.0
10	Combustion, Coal	350	339.68	0.00	0.00	0.4
60	Combustion, Coal	350	468.59	0.00	0.00	0.5
00	Combustion, NEC.	120 - 510	17,396.65	2,813.18	16.17	19.3
	Total Flue Gases	100 - 510	30,777.63	3,133.6	10.18	34.2
	WASTEWATERS					
	Peroxide Bleach	86	2,486			2.7
	Chlorination EFF.	91	4,520			5.0
	Sat. Liq. Water	260	904			1.0
	Sat. Steam	120	7,458			8.3
	Foul Condensate	197	4,294			4.8
	Blow Down	320	255			0.3
	Total Wastewaters	86 -320	26,245			22.2
	Total	86 - 510	57,022	3,133.60	5.50	56.4

① Based On Purchased Fuels & Electricity

② NEDS Data, EPA 450/2-76-005 OAQPS Guidelines

TABLE 24. REGIONAL WASTE HEAT DISCHARGED BY PAPER MILLS (EXC. BLDG. PAPER) (SIC 2621)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	120	7.5		<0.1			
	150	11.8		0.1			
	160	294.7		1.5			
	180	84.2		0.4			
	200	31.6		0.2			
	250	1,028.1		5.4			
	270	304.6		1.6			
	300	1,921.2		10.2			
	310	1,759.2		9.2			
	320	379.1		2.0			
	350	4,697.7		24.6			
	360	642.1	22.9	3.4	0.1		
	370	112.3	7.7	0.6	<0.1		
	400	3,407.5	532.4	17.8	2.8		
	420	916.6	188.7	4.8	1.0		
	450	638.4	172.5	3.3	0.9		
	500	2,888.8	1,031.7	15.1	5.4		
TOTAL		19,125.4	1,955.9			8.2	0.8
2	100	10.8		1.5			
	110	1.4		0.2			
	120	0.5		0.1			
	130	14.0		1.9			
	140	132.8		18.0			
	160	21.2		2.9			
	180	0.8		0.1			
	250	294.1		39.8			
	380	1.7	0.2	0.2	0.0		
	500	94.4	33.7	12.8	4.6		
	1400	167.6	133.3	22.7	18.0		
TOTAL		739.3	167.2			0.3	0.1

(continued)

TABLE 24. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
3	130	16.2		0.1			
	150	104.6		0.4			
	160	96.7		0.4			
	170	92.3		0.3			
	180	31.7		0.1			
	190	61.2		0.2			
	200	76.7		0.3			
	210	18.8		0.1			
	250	1,244.3		4.5			
	260	520.2		1.9			
	270	123.5		0.4			
	280	832.9		3.0			
	300	3,090.0		11.2			
	310	733.9		2.7			
	320	1,051.8		3.8			
	340	114.0		0.4			
	350	611.1		2.2			
	370	569.9	39.3	2.1	0.1		
	380	2,274.5	227.4	8.2	0.8		
	410	477.0	86.7	1.7	0.3		
	460	384.4	111.3	1.4	0.4		
	470	646.4	198.9	2.3	0.7		
	480	1,669.0	542.4	6.0	2.0		
	490	3,369.2	1,150.5	12.2	4.2		
	500	1,922.5	686.6	7.0	2.5		
	520	696.8	269.2	2.5	1.0		
	600	6,792.4	3,265.6	24.6	11.8		
TOTAL		27,622.2	6,577.9			11.9	2.8

TABLE 24. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4	110	1.1		<0.1			
	120	23.8		<0.1			
	130	162.5		0.2			
	140	368.6		0.4			
	150	319.8		0.4			
	160	432.5		0.5			
	170	677.8		0.8			
	180	576.6		0.7			
	190	124.5		0.1			
	200	265.2		0.3			
	210	833.0		0.9			
	220	703.9		0.8			
	230	1,235.9		1.4			
	240	840.2		1.0			
	250	5,286.7		6.0			
	260	1,992.6		2.3			
	270	677.3		0.8			
	280	2,294.9		2.6			
	290	4,476.3		5.1			
	300	2,139.6		2.4			
	310	1,394.3		1.6			
	320	2,254.3		2.6			
	330	4,149.9		4.7			
	340	2,292.1		2.6			
	350	6,063.1		6.9			
	360	2,344.4	83.7	2.7	0.1		
	370	737.9	50.9	0.8	0.1		
	380	334.4	33.4	0.4	<0.1		
	390	2,042.1	263.5	2.3	0.3		
	400	9,520.7	1,487.6	10.9	1.7		
	410	5,544.6	1,008.1	6.3	1.1		
	420	2,351.2	484.1	2.7	0.6		
	430	66.8	15.3	0.1	<0.1		
	440	618.0	154.5	0.7	0.2		
	450	1,789.8	483.7	2.0	0.6		
	460	1,176.5	340.6	1.3	0.4		
	470	4,359.5	1,341.4	5.0	1.5		
	500	3,747.6	1,338.4	4.3	1.5		
	510	627.6	233.5	0.7	0.3		
	550	1,158.5	493.0	1.3	0.6		
	580	1,046.7	481.5	1.2	0.5		
	600	5,729.3	2,754.5	6.5	3.1		
	630	487.6	248.2	0.6	0.3		
	640	35.9	18.6	<0.1	<0.1		
	670	1,185.3	642.9	1.4	0.7		
	680	726.7	399.7	0.8	0.5		
	710	2,404.7	1,374.1	2.7	1.6		
	860	50.0	32.7	0.1	<0.1		
	1800	28.9	29.3	<0.1	<0.1		
TOTAL		87,701.2	13,788.2			37.7	5.9

TABLE 24. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5	100	3.9		<0.1			
	110	10.0		<0.1			
	120	57.5		0.2			
	140	24.7		0.1			
	150	35.8		0.1			
	160	167.1		0.5			
	170	22.1		0.1			
	180	16.1		<0.1			
	200	159.0		0.4			
	230	38.3		0.1			
	250	2,392.1		6.6			
	280	1,138.4		3.1			
	290	65.4		0.2			
	300	850.7		2.3			
	310	510.9		1.4			
	320	754.9		2.1			
	330	175.5		0.5			
	340	1,974.5		5.4			
	350	10,242.9		28.1			
	360	308.6	11.0	0.8	<0.1		
	370	1,684.3	116.2	4.6	0.3		
	380	1,935.6	193.6	5.3	0.5		
	390	1,417.1	182.9	3.9	0.5		
	400	4,793.5	749.0	13.1	2.1		
	410	651.5	118.5	1.8	0.3		
	430	1,405.7	321.3	3.9	0.9		
	440	343.3	85.9	0.9	0.2		
	450	675.3	182.5	1.9	0.5		
	470	1,225.2	376.9	3.4	1.0		
	480	143.1	46.5	0.4	0.1		
	490	181.8	62.1	0.5	0.2		
	500	913.6	326.3	2.5	0.9		
	510	260.2	96.8	0.7	0.3		
	520	87.3	33.7	0.2	0.1		
	550	152.0	64.7	0.4	0.2		
	570	883.7	396.7	2.4	1.1		
	600	759.0	364.9	2.1	1.0		
TOTAL		36,460.6	3,729.5			15.7	1.6

TABLE 24. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6	100	0.1		<0.1			
	110	0.3		<0.1			
	120	13.6		<0.1			
	130	6.9		0.1			
	140	30.4		0.1			
	150	204.6		0.5			
	160	590.2		1.4			
	170	1,051.5		2.5			
	180	130.3		0.3			
	190	36.2		0.1			
	200	476.8		1.1			
	210	21.2		<0.1			
	220	390.6		0.9			
	230	416.1		1.0			
	240	835.3		2.0			
	250	1,915.2		4.5			
	260	834.5		2.0			
	270	614.5		1.4			
	280	447.2		1.1			
	290	629.0		1.5			
	300	3,254.8		7.7			
	310	1,330.7		3.1			
	320	1,602.4		3.8			
	330	1,501.5		3.5			
	340	2,919.3		6.9			
	350	7,307.8		17.2			
	360	133.2	4.8	0.3	<0.1		
	370	2,391.6	164.9	5.6	0.4		
	380	750.1	75.0	1.8	0.2		
	400	856.9	133.9	2.0	0.3		
	410	61.9	11.2	0.1	<0.1		
	420	4,023.8	828.4	9.5	1.9		
	430	820.9	187.3	1.9	0.4		
	450	1,049.1	283.5	2.5	0.7		
	520	1,298.1	501.6	3.1	1.2		
	530	401.8	160.7	0.9	0.4		
	540	1,055.4	435.9	2.5	1.0		
	550	263.2	112.0	0.6	0.3		
	600	320.6	154.1	0.8	0.4		
	610	352.3	172.8	0.8	0.4		
	700	1,073.1	605.8	2.5	1.4		
	710	1,100.4	628.8	2.6	1.5		
TOTAL		42,513.4	4,460.7			18.3	1.9

TABLE 24. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PRECENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
8	140	149.4		5.1			
	150	17.7		0.6			
	160	44.5		1.5			
	170	19.7		0.7			
	190	118.3		4.0			
	250	132.5		4.5			
	390	788.3	101.7	26.8	3.5		
	410	1,670.0	303.6	56.8	10.3		
TOTAL		2,940.4	405.3			1.3	0.2
9	250	44.4		4.5			
	420	940.2	193.6	95.5	19.7		
TOTAL		984.6	193.6			0.4	0.1
10	100	1.8		<0.1			
	110	49.2		0.3			
	150	158.0		1.1			
	170	149.4		1.0			
	250	649.8		4.5			
	280	577.9		4.0			
	300	711.1		4.9			
	350	1,310.7		9.1			
	400	264.2	41.3	1.8	0.3		
	440	828.2	207.0	5.7	1.4		
	450	541.1	146.2	3.8	1.0		
	470	192.3	59.1	1.3	0.4		
	500	795.9	284.3	5.5	2.0		
	560	8,194.8	3,585.2	56.8	24.9		
TOTAL		14,424.4	4,323.1			6.2	1.9

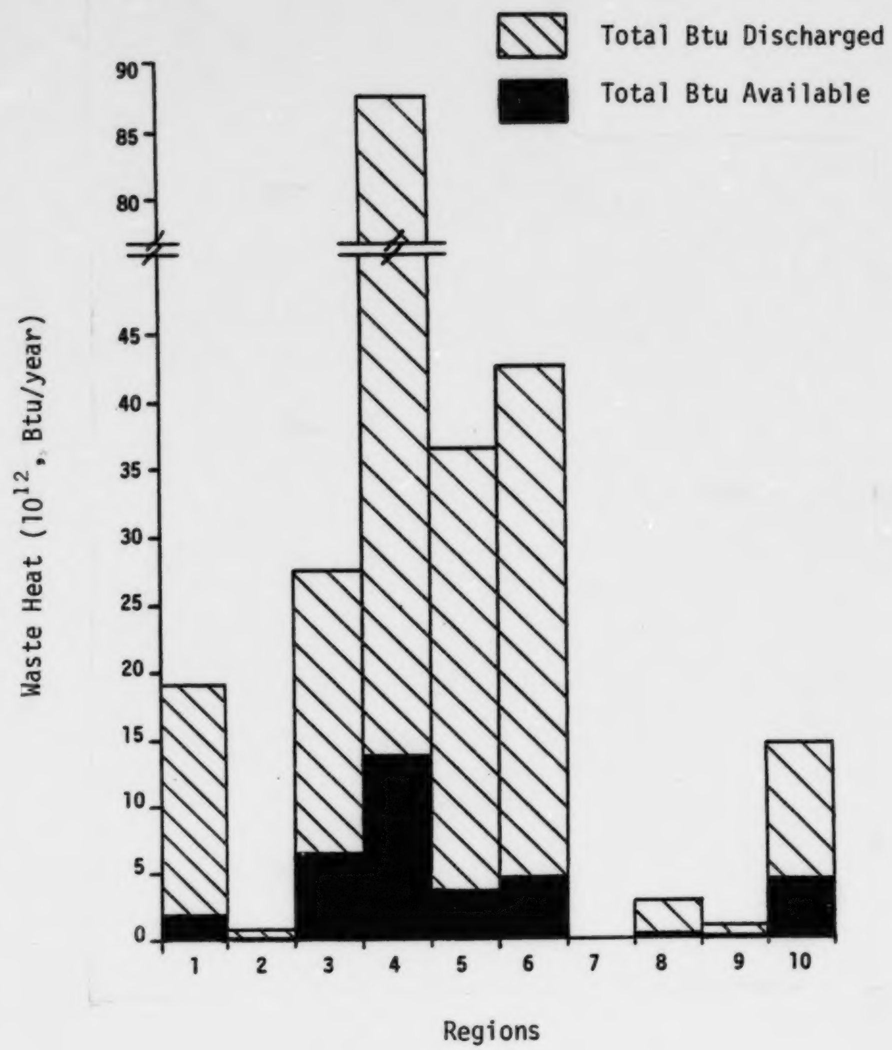

Figure 19. Regional totals for Paper Mills (exc. bldg. paper) (SIC 2621), (1977).

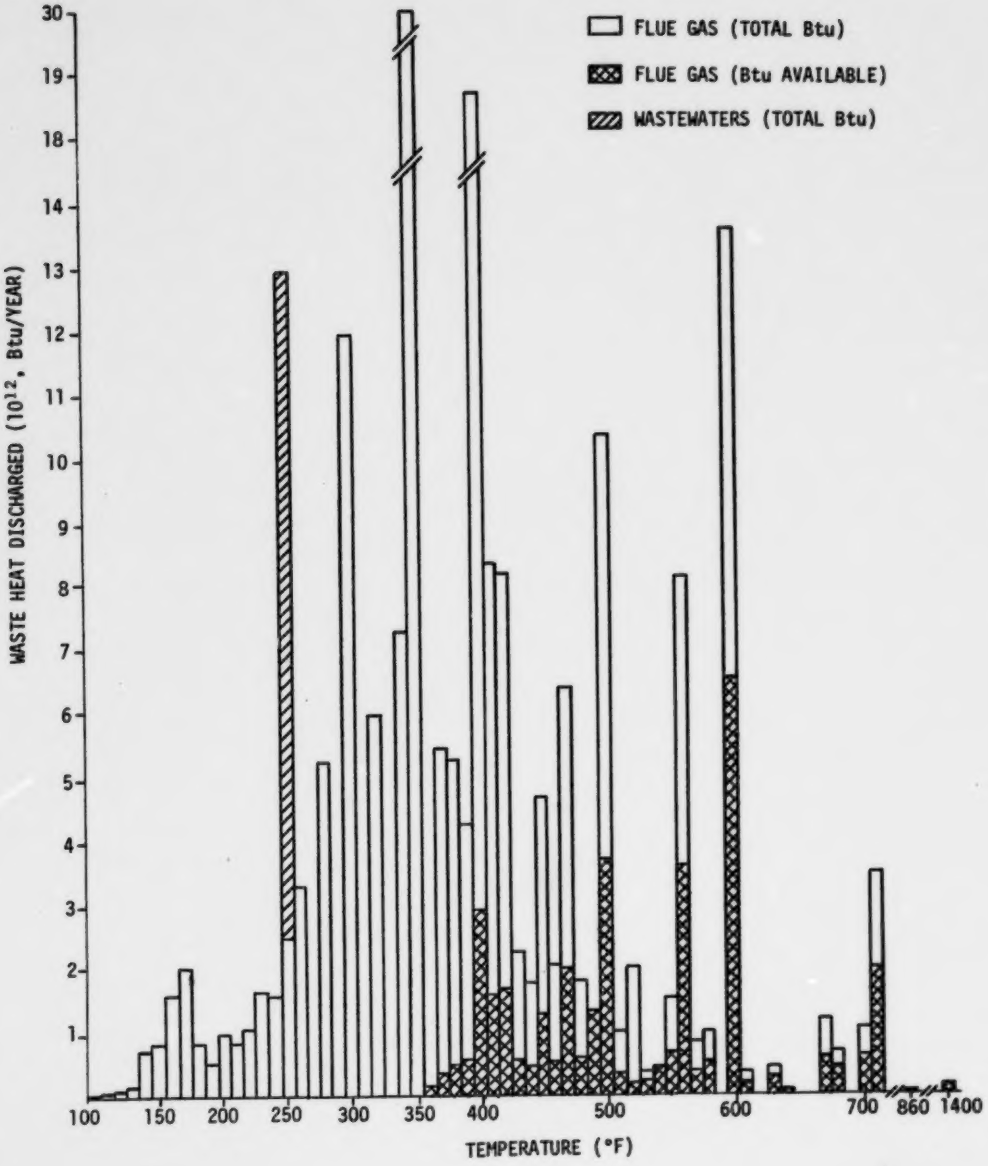

Figure 20. Waste heat temperature profile for Paper Mills (exc. bldg. paper) (SIC 2621).

TABLE 25. TOTAL WASTE HEAT DISCHARGED BY PAPERBOARD MILLS (SIC 2631)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($x10^9$)	TOTAL Btu AVAILABLE ($x10^9$)	% Btu AVAILABLE	% WASTE HEAT ①
	FLUE GASSES					
BL	Process, NEC	100 - 500	7,298.61	501.01	6.86	1.40
1	Recovery Boiler	450	401.07	64.47	16.07	0.10
2	Smelt Dissolving TK	150 - 400	557.67	35.69	6.40	0.10
3	Lime Kiln	150 - 180	566.39	0.00	0.00	0.10
4	Fluid Bed Calciner	120 - 400	9,964.69	247.69	2.48	1.90
18	Unidentified	200	9.79	0.00	0.00	0.00
20	Combustion, Coal	340	316.61	0.00	0.00	0.10
60	Combustion, Coal	570	111.92	50.25	44.89	0.00
70	Combustion, Coal	320	182.50	0.00	0.00	0.00
80	Combustion, Coal	300 - 530	979.33	173.78	17.74	0.20
00	Combustion, NEC.	130 - 1000	24,761.15	5,286.57	21.35	4.80
	Total Flue Gases	100 - 1000	45,149.71	6,359.47	14.09	8.70
	Wastewaters					
	Sat. Wastewater	250	8,960.34			1.70
	Total	100 - 1000	54,110.50	6,359.47	11.75	10.47

① Based On Purchased Fuels & Elec.

② NEDS Data - EPA 450/2-76-005 OAQPS Guidelines

TABLE 26. REGIONAL WASTE HEAT DISCHARGED BY PAPERBOARD MILLS (SIC 2631)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	240	20.6		3.5			
	250	96.6		16.6			
	300	90.6		15.5			
	320	58.8		10.1			
	370	5.4	0.4	0.9	0.1		
	400	29.7	4.6	5.1	0.8		
	420	136.0	28.0	23.3	4.8		
	600	59.9	28.8	10.3	4.9		
	650	85.6	45.0	14.7	7.7		
TOTAL		583.2	106.8	18.3		1.1	0.2
2	110	1.6		1.2			
	110	1.6		1.2			
	130	5.2		3.9			
	180	14.0		10.4			
	200	84.0		62.7			
	210	5.4		4.0			
	250	22.2		16.6			
TOTAL		134.0				0.2	
3	130	9.5		0.1			
	170	82.0		1.0			
	200	35.0		0.4			
	210	129.9		1.6			
	240	20.4		0.2			
	250	1,369.8		16.6			
	270	1,083.5		13.1			
	300	14.3		0.2			
	320	232.7		2.8			
	330	219.9		2.7			
	360	1,826.1	65.2	22.1	0.8		
	400	376.1	58.8	4.5	0.7		
	420	30.7	6.3	0.4	0.1		
	440	1,091.1	272.8	13.2	3.3		
	450	870.1	235.2	10.5	2.8		
	520	769.4	297.3	9.3	3.6		
	570	111.9	50.3	1.4	0.6		
TOTAL		8,272.4	985.9		11.9	15.3	1.8

(continued)

TABLE 26. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4	100	4.4		<0.1			
	120	44.6		0.1			
	130	449.4		1.2			
	140	67.3		0.2			
	150	181.4		0.5			
	160	316.1		0.8			
	170	515.6		1.3			
	180	119.5		0.3			
	190	15.4		<0.1			
	230	246.4		0.6			
	250	6,453.9		16.6			
	260	630.0		1.6			
	270	603.7		1.5			
	280	629.9		1.6			
	300	3,047.3		7.8			
	310	1,727.5		4.4			
	320	617.8		1.6			
	340	1,101.5		2.8			
	350	2,687.4		6.9			
	380	3,589.4	358.9	9.2	0.9		
	390	250.5	32.3	0.6	0.1		
	400	3,476.6	543.2	8.9	1.4		
	410	2,026.0	368.4	5.2	0.9		
	420	1,148.6	236.5	2.9	0.6		
	450	3,411.4	922.0	8.8	2.4		
	480	963.9	313.3	2.5	0.8		
	490	1,158.1	395.4	3.0	1.0		
	500	371.2	132.6	1.0	0.3		
	530	334.3	133.7	0.9	0.3		
	550	685.5	291.7	1.8	0.7		
	570	333.2	149.6	0.9	0.4		
	630	696.8	354.7	1.8	0.9		
	800	1,069.4	668.4	2.7	1.7		
TOTAL		38,974.0	4900.7			72.0	9.1

TABLE 26. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5	250	339.1		16.1			
	320	182.5		8.9			
	340	318.6		15.6			
	350	885.0		43.2			
	370	256.7	17.1	12.5	0.9		
	480	0.2	<0.1	<0.1	<0.1		
	490	65.4	22.3	3.2	1.1		
TOTAL		2,047.5	40.0			3.8	0.1
6	140	6.0		0.1			
	170	26.8		0.7			
	180	302.2		7.4			
	250	840.0		20.5			
	300	441.3		10.8			
	310	1,147.4		28.0			
	320	273.7		6.7			
	330	160.0		3.9			
	410	396.7	72.1	9.7	1.8		
	460	94.7	27.4	2.3	0.7		
	600	254.4	122.3	6.2	3.0		
	1000	147.5	104.2	3.6	2.5		
TOTAL		4,091.3	326.0			7.6	0.6
10.	250	1.3		16.7			
	300	6.5		83.3			
TOTAL		7.8				<0.1	-0-

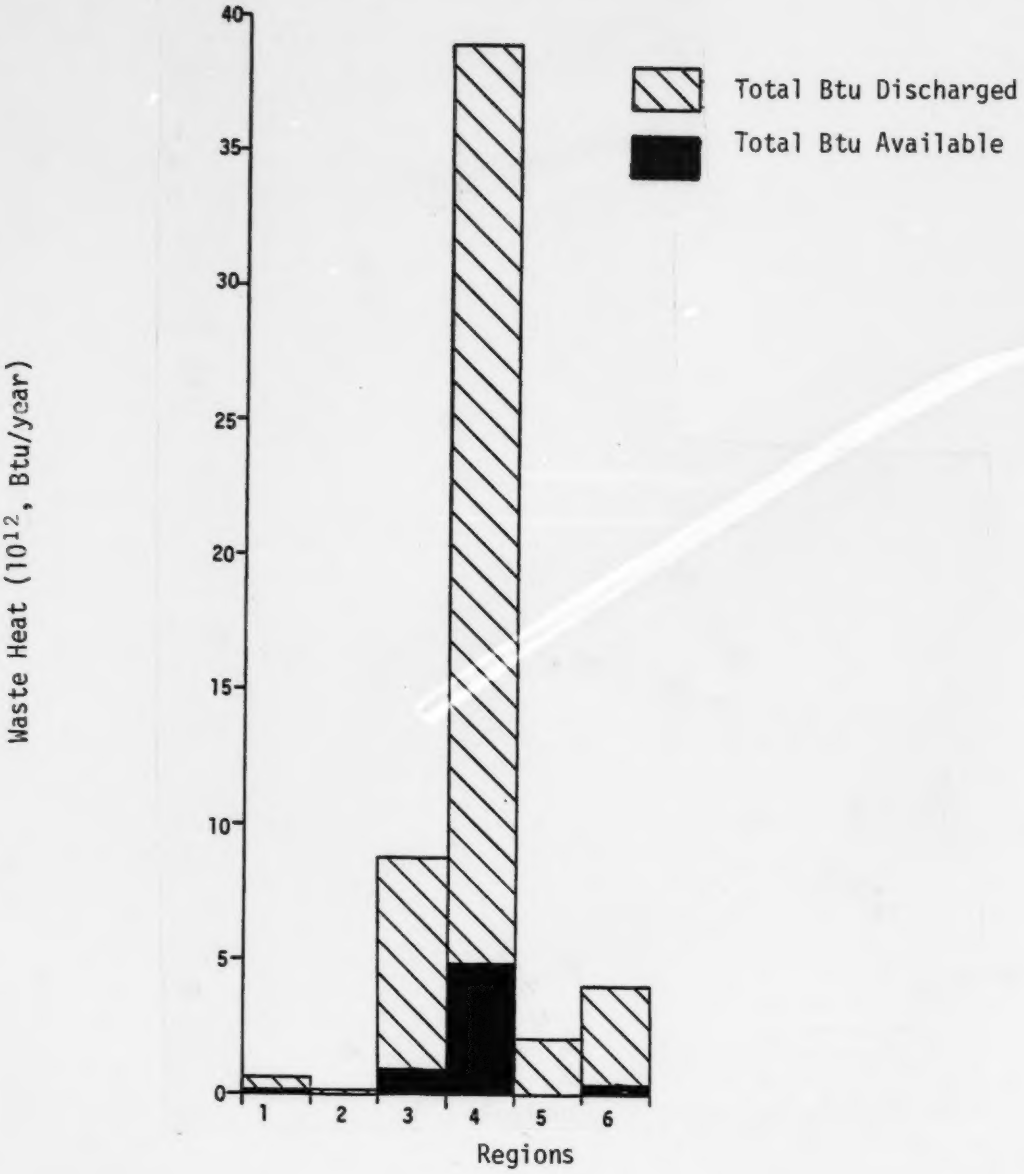

Figure 21. Regional totals for Paperboard Mills (SIC 2631), (1977).

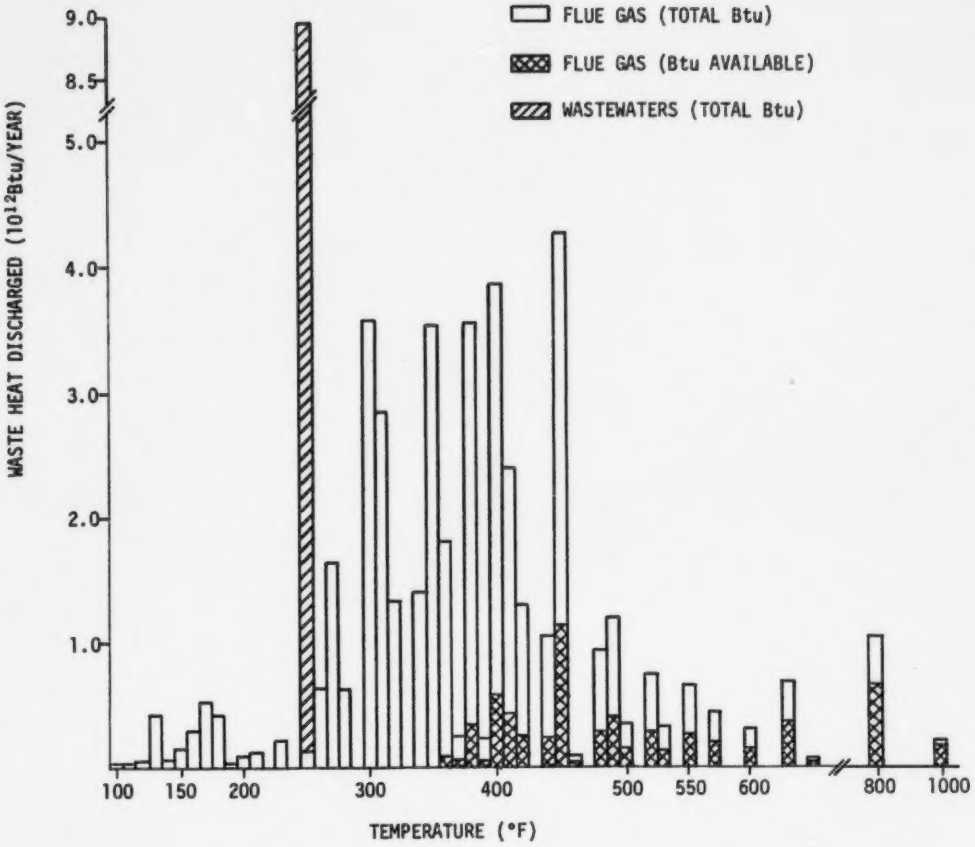

Figure 22. Waste heat temperature profile for Paperboard Mills (SIC 2631).

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SECTION 6

STONE, CLAY AND GLASS

BASIC GLASS (SIC 3211, 3221, 3229)

Introduction

Basic glass industries consist of the name given to a combination of the Flat Glass Industry, SIC 3211, the Glass Container Industry, SIC 3221, and the Pressed and Blown Glass Industry, SIC 3229. These industries were combined because all three utilize the same process for the major energy intensive operations (i.e., glassmaking), which is then shaped into the products of the separate industries.

Manufacture of a basic sheet of flat glass, from sand and other raw materials, is defined as primary flat glass manufacturing. Sheet, rolled, plate, and float glass are primary flat glass products. These glass sheets may be used directly or may be fabricated into glass products such as mirrors, automotive and architectural tempered glass, windshields, and numerous specialty products.

Glass container manufacturing consists of melting raw materials and then forming the molten glass using a blowmold technique. The industry comprises establishments primarily engaged in manufacturing glass containers for commercial packing and bottling and for home canning The major products that commercially packed glass containers hold are food, beverages, medicines and toiletries. The industry uses "narrow neck" and "wide mouth" for its main classifications.

Pressed and blown glass manufacturing consists of melting raw materials and then forming the molten glass by pressing and blowing techniques to manufacture a variety of products. The pressed and blown glass industry has been subcategorized as machine pressed and blown glass manufacturing of tableware, lenses, reflectors, sealed headlamp glass parts, and other products not included in the other subcategories; glass tubing manufacturing; television picture tube envelope manufacturing; incandescent lamp envelope manufacturing; and hand pressed and blown glass manufacturing. Production methods and wastewater characteristics are the primary bases for subcategorization. Hand pressed and blown glass manufacturing are also included in SIC 3229, but because it represents such a small percentage of the total output and utilizes a variety of finishing techniques it was not included in the wastewater discussions. In the United States glass industry, approximately 90% of all glass is melted in regenerative furnaces. These furnaces are fired with natural gas as the primary fuel. Today, two types of regenerative furnaces are used: side port, and end port. In this country more glass is melted in the side port furnace because of its higher pull rates.

Presently in the United States more than 50 different glass compositions are being melted. However, about 95% of the total tonnage shipped consists of sodalime glass. The major raw materials which make up sodalime glass are silica sand, feldspar, dolomite, limestone, and soda ash.

Geographical Distribution

The bulk of glass production in the United States is concentrated in the Northeast, Central, Middle Atlantic, and Pacific regions. The major glass producing states are Illinois, Ohio, Pennsylvaia, New York, West Virginia, New Jersey and California.

There are approximately 30 firms with a total of 140 plants presently manufacturing glass containers in the United States. The average plant capacity is 427 tons which range from 134 to 1,450 tons pulled per day. Plants are located throughout the United States to service regional customers, but a large number are concentrated in the northeastern United States.

The production of sheet, plate, and float glass in the United States is highly concentrated and involves only seven companies. Most flat glass plants are located in the Northeast and the Middle Atlantic States and were originally established there because of raw material and fuel accessibility.

There are about 50 machine pressed and blown glass manufacturing plants in the United States. The average capacity is 100 tons pulled per day with a range of from 44 to 384 tons pulled per day. About 30 plants manufacture glass tubing with production ranges of from 44 to 180 tons pulled per day, averaging about 110. Television picture envelopes are manufactured in about 10 plants. Plant production varies from 156 to 280 tons pulled per day and average daily production is 229 tons pulled per day. Incandescent lamp envelopes are manufactured at 18 plants. Plant production ranges from 155 to 270 tons pulled per day, with an average of 212 tons pulled per day.

Energy Consumption

In 1974 the basic glass industries purchased 2.76×10^{14}Btu of fuel and electric energy for heat and power. This represents approximately 2% of the total purchased energy of manufacturing industries.

Form of Energy Used

The six forms of energy used by the glass manufacturing industry are natural gas, electricity, distillate fuel oil, residual fuel oil, propane, and coal. Overall, the industry average use is as follows:

	Percent of Total
Natural Gas	70.2
Electricity	20.6
Distillate Fuel Oil	4.6
Residual Fuel Oil	3.9
Propane	0.3
Coal	0.4

Oil and propane are the usual standby or substitute fuels, for the melting processes.

In the United States, natural gas has been used as the primary source of energy for many years because it was a low cost, available, clean, easy to handle fuel. In 1973, it accounted for about 70% of the total energy used in a glass plant. The principal use of natural gas in the integrated glass plant is in the melting function, which consumes from 60% to 80% of the total energy used in a typical glass plant. The specific requirement depends on the product and type of glass. In addition, annealing is carried out as a postforming operation, and natural gas for this operation accounting for up to to 10% of the total plant energy consumption.

Point Sources of Waste Heat

The major sources of waste heat in glass manufacturing are, stack gases from melting and annealing furnaces, non-contact cooling waters for bath feeders, melting furnaces, forming machines, annealing lehrs compressors, other auxiliary equipment, and process waters for finishing operations and contact cooling. Since all combustion and process off-gases are incorporated in the following tables, this section will discuss only wastewaters.

In glass manufacturing, broken scrap glass, called cullet, is produced. Principal sources are product rejects, breakage, or intentional wasting of molten glass during production interruptions. The addition of cullet improves the melting qualities of the batch because of its tendency to melt faster than the other ingredients, thus providing starting points from which the melting can proceed. Cullet quench waters are required to dissipate the heat of molten glass or to quench hot pieces which are imperfect. These waters are usually combined with non-contact cooling waters before discharge.

Process waters for contact cooling, such as cullet quenching and finishing operations, vary substantially between the different product operations. This variance is most pronounced within the pressed and blown glass industry category because of product diversity. Table 27 presents the average heat rejection values for the different product operations within SIC 3229.

TABLE 27. COOLING AND PROCESS WATERS FOR WASTE HEAT (SIC 3229)

PRODUCT	STREAM	FLOW (Gal/Ton)	T (ΔF)	WASTE HEAT (Btu/Ton)
Pressed & Blown	Non-Contact & Cullet Quench	1350	18	2.03×10^5
Glass Tubing	Non-Contact & Cullet Quench	2000	8	1.34×10^5
T.V. Tubes	Finishing Non-Contact Cullet Quench	3000	25	6.26×10^5
Incandescent Lights	Non-Contact Cullet Quench	1080	14	1.26×10^5
Frosting		950	20	1.03×10^5

Non-Contact Cooling And Process Waters

Flat glass production rejects more heat per ton of product than the glass container and pressed and blown glass industries combined. For this study, sheet and float glass operations were investigated because they represent majority of glass produced within SIC 3211. Because plate glass is being replaced by the float glass process, it justified eliminating this process from our data search.

The major source of heat rejection, in flat glass manufacturing, consists of noncontact cooling waters since there are minimal process wastewaters produced. Average heat rejection is 2 x 10^6Btu/ton, with differential temperatures ranging from 10°F to 40°F and flow rates ranging from 500 gallons to 20,000 gallons/ton. Temperatures and flow rates are highly dependent on the amount of once-through non-contact cooling and water conservation practices. Based upon average heat rejection rates it has been estimated that non-contact cooling waters contribute about 20% of the waste heat discharged within SIC 3211.

In glass container manufacturing, non-contact cooling waters and cullet quench waters are highly variable. Combined flows may reach 1500 gallons/ton Typical differential temperatures and flow are 11°F and 700 gallons/ton with average heat rejections of 64,256 Btu/ton.

Pressed and blown glass consists of several subcategories which utilize water for non-contact cooling, cullet quenching, and finishing techniques. Non-contact cooling and cullet quench waters account for the majority of this water. This results in an average waste heat discharge from these streams of 2.6 x 10^5Btu/ton.

Discussion - Tables and Graphs

Flat Glass Industry, SIC 3211

Table 28 presents the total flue gas waste heat dischargd by the flat glass industry according to its point source. This indicated that this industry discharged almost 75% of its purchased fuels and electricity as flue gases. Non-contact cooling waters account for an additional 20% of the purchased fuels and electricity. Almost 60% of the energy contained in the waste heat flue gas was discharged at temperatures above 350°F (177°C).

Table 29 presents a breakdown of the total flue gas waste heat discharges, by EPA region and discharge temperature. EPA region 4 discharged greater than 50% of the total waste heat discharged by the flat glass industry. A summary of the regional waste heat discharged is presented in Figure 23.

The flue gas waste heat temperature profile for the flat glass industry is presented in Figure 24. This indicates that the most significant discharge temperatures for this industry were: 900°F, 1150°F, and 1230°F. Together these discharges accounted for 51% of the total flue gas waste heat being discharged by the flat glass industry.

Glass Container Industry, SIC 3221

The glass container industry discharged approximately 35% of its purchased fuel and electricity as flue gas discharged. Table 30 presents the total flue gas waste heat discharged by the glass container industry. A breakdown of this discharged waste heat is presented in Table 31. This table indicates that 48% of the industries flue gas waste heat was discharged in EPA region 5. The total flue gas waste heat discharged is summarized in Figure 25. This figure indicates that EPA regions 2 and 4 together account for almost 75% of the total flue gas waste heat discharged by the glass container industry.

Figure 26 presents the flue gas waste heat temperature profile for the glass container industry. The most significant discharge temperatures are at 800°F and 850°F. Together they contribute approximately 25% of the total flue gas waste heat discharged by the glass container industry.

Pressed and Blown Glass, SIC 3229

The pressed and blown glass industry discharged approximately 30% of their purchased fuels and electricity as flue gas waste heat. Table 32 presents this data according to process classification. Process NEC includes all manufacturing processes within SIC 32 which are "Not Elsewhere Classified". Due to the variety of differing process operations used in the manufacturing of pressed and blown glass, this process category accounts for over half of the total flue gas waste heat discharged for this industry.

Table 33 presents a breakdown, of the total flue gas waste heat discharged, by EPA regions and discharge temperatures. EPA region 5 contributed almost half of the total flue gas waste heat discharged by the pressed and blown glass industry. A summary of the total EPA region discharges of flue gas waste heat is presented in Figure 27.

Figure 28 presents the flue gas waste heat temperature profile for the pressed and blown glass industry. The most significant discharge temperature was 600°F, which accounted for almost 20% of the total waste heat discharged.

TABLE 28. TOTAL WASTE HEAT DISCHARGED BY FLAT GLASS (SIC 3211)

② IPP #	DESCRIPTION	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	% Btu Available	%Waste Heat ①
	Flue Gas					
BL	Process, NEC	120-2800	12963.04	7059.88	54.46	23.78
1	Glass Melting	100-950	20560.28	12591.85	61.24	37.72
38	Combustion, NEC	700	585.26	330.39	56.45	1.07
60	Combustion, Coal	350-550	164.12	34.99	21.32	0.30
99	Combustion, NEC	100-900	307.41	157.35	51.19	0.56
00	Combustion, NEC	150-1230	6102.26	3583.38	58.72	11.19
	Total Flue Gases	100-2800	40,682.37	23,757.84	58.40	74.64

① Based on purchased fuel & electricity

② NEDS data, EPA/2076-005 OAQPS guidelines

TABLE 29. REGIONAL WASTE HEAT DISCHARGED BY FLAT GLASS (FLUE GASES ONLY) SIC (3211)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	37.5		3.3			
	150	1.8		0.2			
	180	35.4		3.2			
	300	22.9		2.0			
	600	787.9	378.8	70.3	33.8		
	900	234.6	157.3	20.9	14.0		
TOTALS		1120.0	536.1			2.7	1.3
3	120	6.7		0.1			
	150	15.8		0.2			
	290	12.1		0.2			
	300	41.9		0.6			
	350	1629.4		22.9			
	360	3.5	0.1	0.1	0.1		
	400	138.0	21.6	1.9	0.3		
	420	88.7	18.3	1.2	0.3		
	450	681.9	184.3	9.6	2.6		
	490	52.2	17.8	0.7	0.3		
	500	0.7	0.2	0.1	0.1		
	600	309.1	148.6	4.3	2.1		
	620	791.4	395.7	11.1	5.6		
	650	186.3	98.0	2.6	1.4		
	750	21.8	13.0	0.3	0.2		
	770	722.3	439.7	10.2	6.2		
	780	165.3	101.6	2.3	1.4		
	820	265.4	168.6	3.7	2.4		
	900	1252.4	840.0	17.6	11.8		
	1000	4.1	2.9	0.1	0.1		
	1200	159.3	120.9	2.2	1.7		
	1250	152.7	117.5	2.1	1.7		
	2800	411.5	370.6	5.8	5.2		
TOTALS		7112.4	3059.4			17.4	7.5
4	100	160.0		0.8			
	110	1.3		0.1			
	120	173.6		0.8			
	160	4.9		0.1			
	290	36.2		0.2			
	300	75.5		0.4			
	320	97.9		0.5			
	330	53.3		0.3			
	360	146.5	5.2	0.7	0.1		
	370	287.3	19.8	1.4	0.1		
	380	314.0	31.4	1.5	0.2		

(continued)

TABLE 29. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont)	520	33.1	12.8	0.2	0.1		
	550	385.5	164.0	1.8	0.8		
	590	1486.4	699.5	7.1	3.3		
	640	3.6	1.8	0.1	0.1		
	650	72.1	38.0	0.3	0.2		
	750	183.4	109.5	0.9	0.5		
	770	270.9	164.9	1.3	0.8		
	840	522.7	337.0	2.5	1.6		
	850	592.6	384.8	2.8	1.8		
	860	1112.7	727.5	5.3	3.5		
	900	13842.4	9284.5	66.2	44.4		
	940	1036.7	711.2	5.0	3.4		
	950	9.8	6.7	0.1	0.1		
TOTALS		20902.5	12698.8			51.0	31.0
5	520	384.5	148.6	8.6	3.3		
	760	206.5	124.5	4.6	2.8		
	960	1916.1	1328.2	42.8	29.7		
	1150	1968.0	1471.4	44.0	32.9		
TOTALS		4475.1	3072.7			10.9	7.5
6	320	796.4		42.0			
	920	268.6	182.3	14.2	9.6		
	1150	832.2	622.2	43.9	32.8		
TOTALS		1897.2	804.5			4.6	2.0
7	350	81.9		100			
TOTALS		81.9				0.2	-
9	600	71.8	34.5	1.3	0.6		
	670	914.8	496.2	16.9	9.2		
	700	585.3	330.4	10.8	6.1		
	740	268.3	158.5	5.0	2.9		
	820	305.4	193.9	5.6	3.6		
	860	347.0	206.9	6.4	3.8		
	1230	2909.0	2226.0	53.9	41.2		
TOTALS		5401.6	3666.4			13.2	8.9

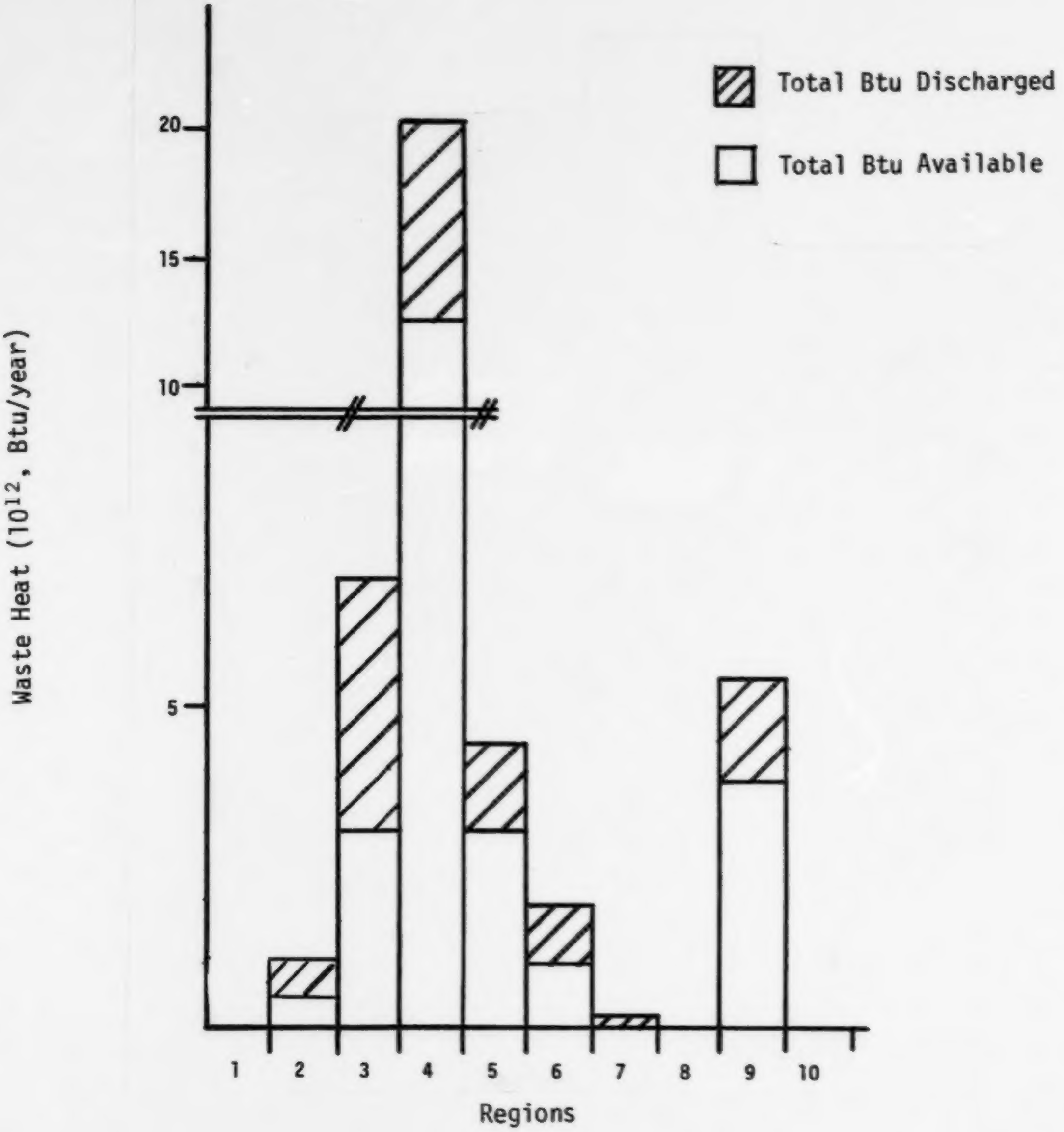

Figure 23. Regional totals for Flat Glass (flue gases only) (SIC 3211), (1977).

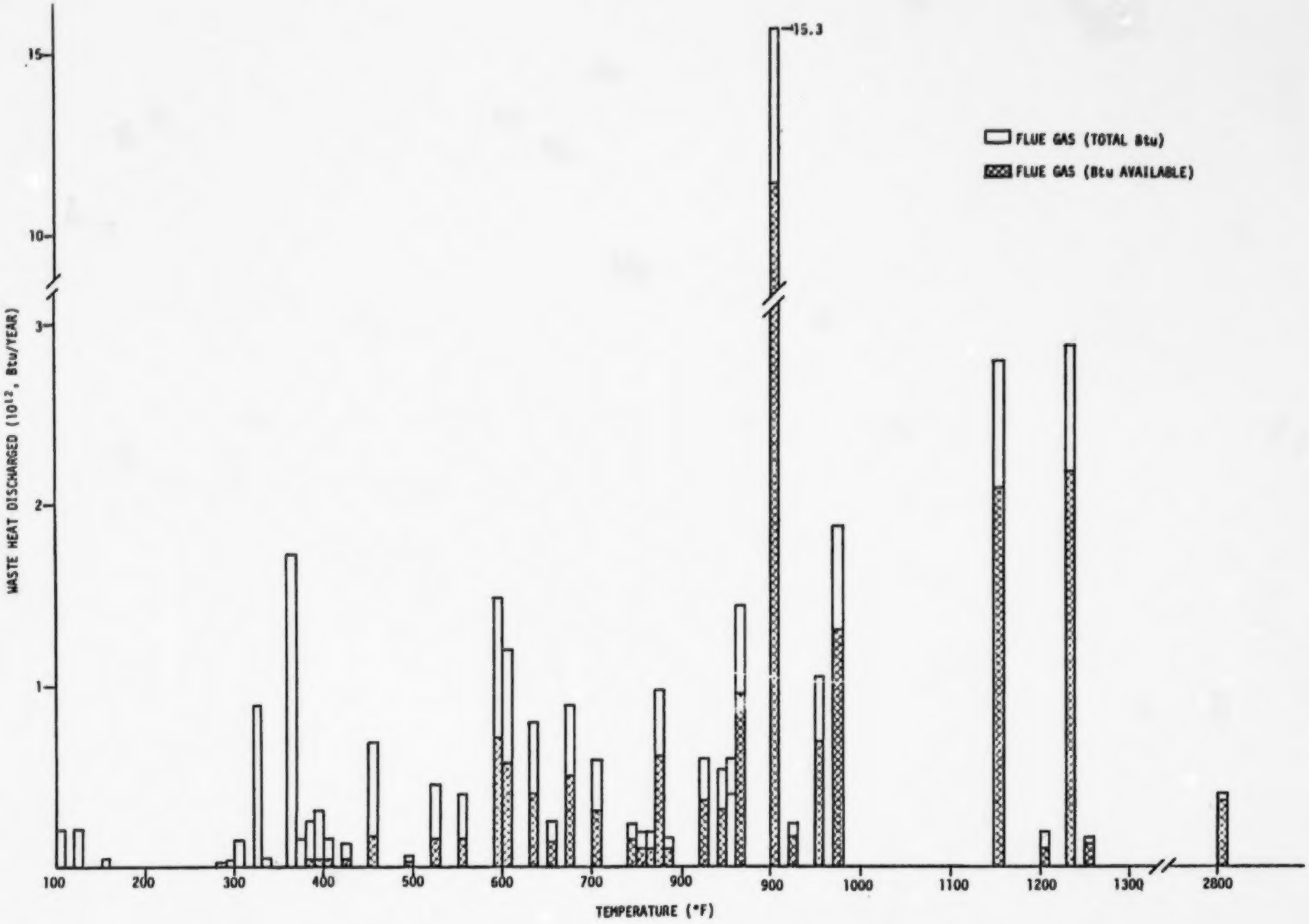

Figure 24. Waste heat temperature profile for Flat Glass (SIC 3211), (flue gases only).

TABLE 30. TOTAL WASTE HEAT DISCHARGED BY GLASS CONTAINERS (SIC 3221)

② IPP #	Description	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available	% Btu Available	%Waste① Heat
	Flue Gases					
BL	Process, NEC	100-1180	12674.06	6845.01	54.01	8.45
1	Glass Melting	100-1200	30468.38	17661.81	57.98	20.31
99	Combustion, NEC	420- 870	1698.21	557.94	32.85	1.13
00	Combustion, NEC	120-1090	8244.10	2920.90	35.43	5.45
	Total Flue Gases	100-1200	53084.75	27985.66	52.72	35.34

1 Based on purchased fuel & energy

2 NEDS data, EPA/2-76-005 OAQPS Guidelines

TABLE 31. REGIONAL WASTE HEAT DISCHARGED BY GLASS CONTAINERS (FLUE GASES ONLY) (SIC 3221)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	1.0		<0.1			
	120	8.2		0.1			
	250	23.0		0.2			
	300	49.6		0.4			
	400	1508.3	235.7	11.3	1.8		
	420	531.3	109.4	4.0	0.8		
	450	918.4	248.2	6.9	1.9		
	460	144.7	41.9	1.1	0.3		
	500	562.8	201.0	4.2	1.5		
	510	212.5	79.1	1.6	0.6		
	570	205.8	92.4	1.5	0.7		
	580	265.7	122.2	2.0	0.9		
	600	439.6	211.4	3.3	1.6		
	620	7.8	3.9	0.1	0.1		
	640	16.0	8.3	0.1	0.1		
	650	520.8	274.1	3.9	2.0		
	670	256.6	139.2	1.9	1.0		
	690	198.6	110.7	1.5	0.8		
	700	656.6	370.7	4.9	2.8		
	740	36.9	21.8	0.3	0.2		
	750	121.3	72.4	0.9	0.5		
	770	282.0	171.6	2.1	1.3		
	800	729.2	455.8	5.4	3.4		
	850	5466.3	3549.6	40.9	26.5		
	870	213.3	140.4	1.6	1.0		
TOTALS		13376.4	6659.6			25.2	12.5
3	280	298.7		5.9			
	300	13.4		0.3			
	400	1561.7	244.0	31.0	4.8		
	600	1110.0	533.6	22.0	10.6		
	700	389.8	220.0	7.7	4.4		
	750	68.7	41.0	1.4	0.8		
	800	1506.5	941.5	29.9	18.7		
	1200	96.7	73.4	1.9	1.5		
		5045.4	2053.6			9.5	3.9
4	150	3.6		0.1			
	190	2.1		0.1			
	200	1.1		<0.1			
	450	239.4	64.7	7.3	2.0		
	500	489.6	174.9	15.0	5.4		
	510	140.3	52.2	4.3	1.6		
	600	590.4	283.8	18.1	8.7		

(continued)

TABLE 31. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont)	650	250.7	131.9	7.7	4.0		
	750	322.2	192.4	9.9	5.9		
	770	305.2	185.8	9.4	5.7		
	780	606.9	372.8	18.6	11.4		
	800	0.6	0.4	0.1	0.1		
	940	311.1	213.4	9.5	6.5		
TOTALS		3263.2	1672.3			6.1	3.2
5	100	4.2		<0.1			
	150	51.1		0.2			
	170	20.5		0.2			
	200	4.8		<0.1			
	300	146.2		0.6			
	320	19.6		0.2			
	400	4.8	0.8	<0.1	<0.1		
	410	13.5	2.4	0.1	0.1		
	420	830.5	171.0	3.3	0.7		
	470	364.6	112.2	1.4	0.4		
	500	987.8	352.8	3.9	1.4		
	550	134.7	57.3	0.5	0.2		
	560	1598.5	699.4	6.3	2.7		
	600	123.7	59.5	0.5	0.2		
	650	2089.2	1099.6	8.2	4.3		
	660	401.8	214.7	1.6	0.8		
	670	882.3	478.5	3.5	1.9		
	680	844.4	464.4	3.3	1.8		
	700	1304.6	736.5	5.1	2.9		
	750	849.6	507.2	3.3	2.0		
	790	715.7	443.5	2.8	1.7		
	800	6075.4	3797.1	23.8	14.9		
	810	872.7	549.9	3.4	2.2		
	850	405.6	263.4	1.6	1.0		
	900	1050.2	704.4	4.1	2.8		
	1050	953.9	688.4	3.7	2.7		
	1080	1119.2	817.0	4.4	3.2		
	1090	154.9	113.5	0.6	0.4		
	1100	2034.9	1496.2	8.0	5.9		
	1180	1460.5	1102.0	5.7	4.3		
TOTALS		25519.1	14931.7			48.1	28.1
6	100	1.9		0.1			
	150	5.2		0.3			
	210	4.9		0.3			
	300	8.0		0.5			

TABLE 31. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6(Cont)	400	395.5	61.8	17.6	2.8		
	410	268.3	48.8	12.0	2.2		
	500	440.1	157.2	19.6	7.0		
	700	333.3	188.1	14.9	8.4		
	750	500.1	298.6	22.3	13.3		
	900	14.8	9.9	0.7	0.4		
	1100	270.0	198.5	12.0	8.9		
TOTALS		2242.1	962.9			4.2	1.8
9	380	526.2	52.6	15.8	1.6		
	420	286.4	59.0	8.6	1.8		
	560	310.5	135.9	9.3	4.1		
	570	540.4	242.6	16.2	7.3		
	650	546.3	287.5	16.4	8.6		
	700	31.6	17.9	0.9	0.5		
	720	462.9	267.6	13.9	8.0		
	900	351.5	235.8	10.5	7.1		
	100	282.1	199.3	8.5	6.0		
TOTALS		3338.0	1498.1			6.3	2.8
10	900	135.8	91.1	45.2	30.3		
	1000	164.8	116.5	54.8	38.8		
TOTALS		300.6	207.6			0.6	0.4

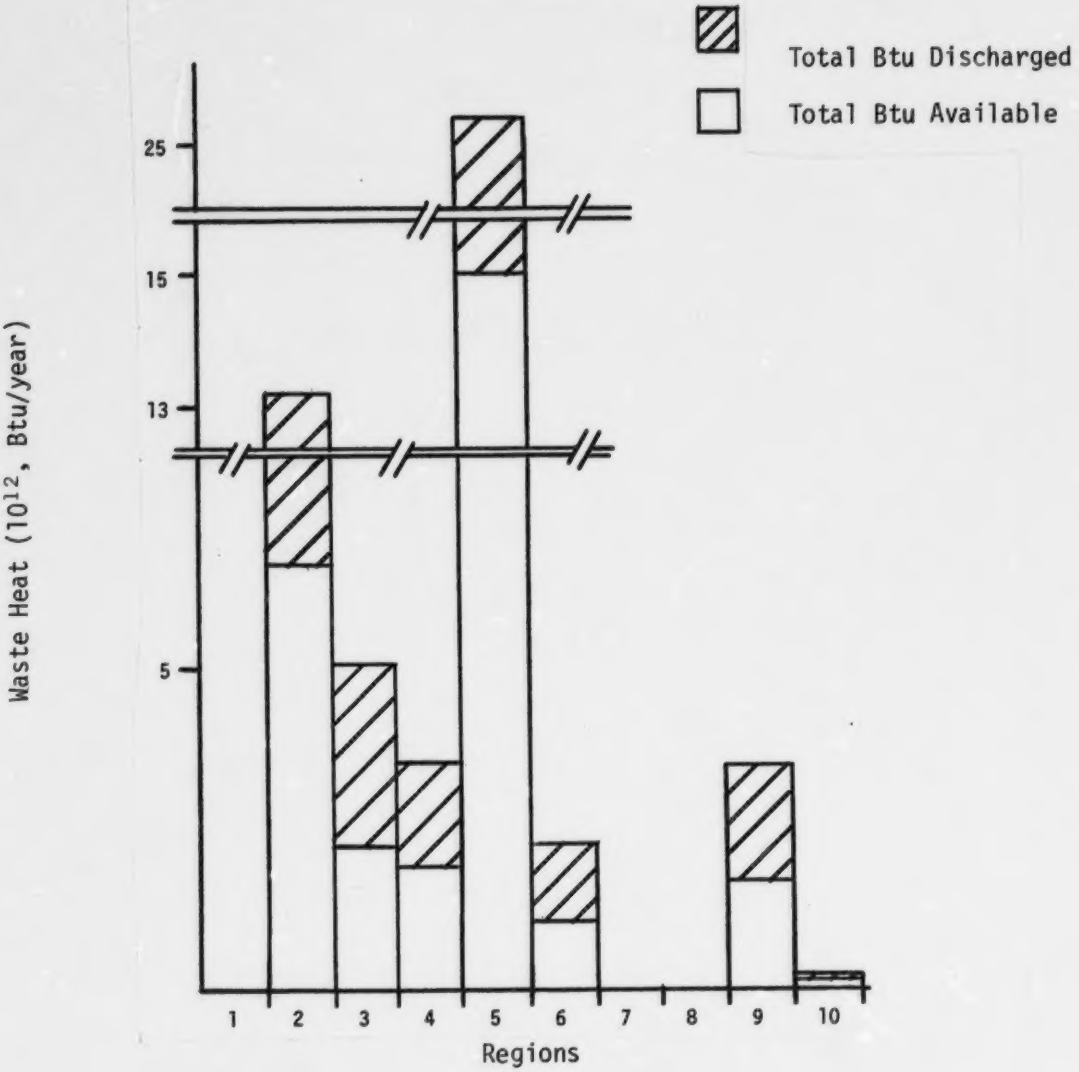

Figure 25. Regional totals for Glass Containers (SIC 3221), (1977).

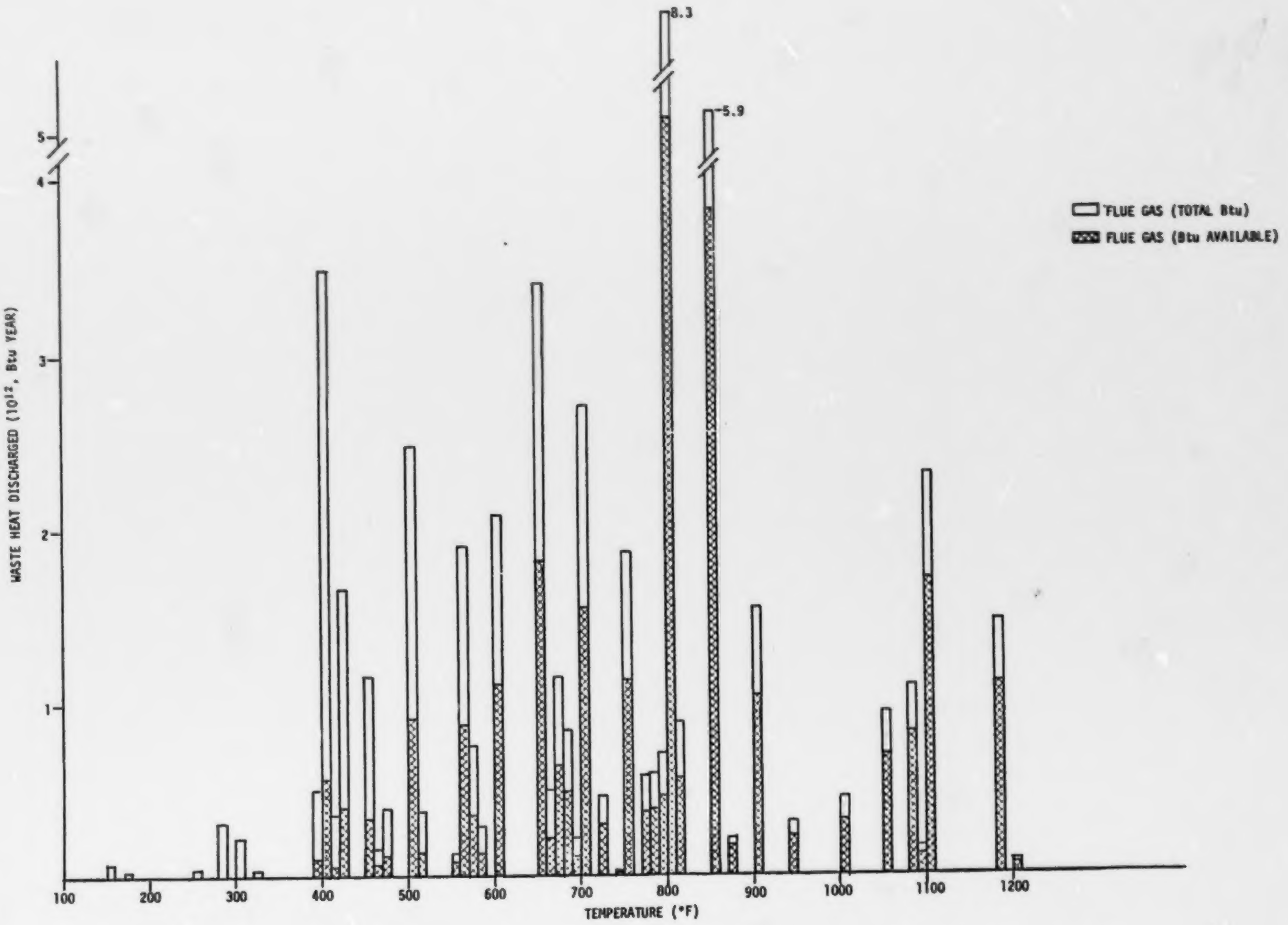

Figure 26. Waste heat temperature profile for Class Containers (SIC 3221).

TABLE 32. TOTAL WASTE HEAT DISCHARGED BY PRESSED AND BLOWN GLASS (SIC 3229)

② IPP #	DESCRIPTIONS	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	% Btu Available	%Waste ① Heat
	Flue Gases					
BL 1 00	Process, NEC	100-1050	13241.30	6322.70	47.75	18.81
	Glass Melting	150-1000	3963.02	2271.70	57.32	5.63
	Combustion, NEC	110-1750	3917.59	1706.12	43.55	5.57
	Total Flue Gases	100-1750	21121.91	10300.52	48.77	30.01

① Based on purchased fuel & electricity

② NEDS data, EPA/2-76-005 OAQPA guidelines

TABLE 33. REGIONAL WASTE HEAT DISCHARGED BY PRESSED AND BLOWN GLASS (FLUE GASES ONLY) (SIC 3229)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	350	58.0		2.6			
	400	322.0	50.3	14.4	2.3		
	420	59.0	12.1	2.6	0.5		
	550	90.3	38.4	4.0	1.7		
	600	261.5	125.7	11.7	5.6		
	650	461.4	242.8	20.6	10.6		
	820	983.4	624.6	44.0	27.9		
TOTALS		2235.7	1094.0			10.6	5.2
2	100	0.8		0.1			
	120	1.1		0.1			
	140	361.9		9.3			
	150	66.1		1.7			
	200	3.0		0.1			
	260	7.1		0.2			
	300	6.2		0.2			
	340	62.8		1.6			
	350	2.8		0.1			
	400	177.5	27.7	4.6	0.7		
	420	90.2	18.6	2.3	0.5		
	450	624.2	168.7	16.1	4.3		
	460	41.1	11.9	1.1	0.3		
	490	340.2	116.2	8.7	3.0		
	500	119.9	42.8	3.1	1.1		
	300	141.5	79.9	3.6	2.1		
	800	307.3	192.1	7.9	4.9		
	810	806.2	508.0	20.7	13.1		
	890	729.2	486.1	18.2	12.5		
TOTALS		3888.9	1651.9			18.4	7.8
4	100	7.4		0.2			
	110	1.3		<0.1			
	120	13.5		0.4			
	130	2.0		0.1			
	140	0.1		<0.1			
	150	10.1		0.3			
	170	2.0		0.1			
	180	47.4		1.6			
	190	6.8		0.2			
	200	2.3		0.1			
	220	13.4		0.4			
	230	77.0		2.5			
	250	13.3		0.4			
	300	18.9		0.6			

(continued)

TABLE 33. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4(Cont)	320	53.1		1,8			
	350	52.6		1.7			
	370	16.5	1.1	0.5	0.1		
	380	23.0	2.3	0.8	0.1		
	400	47.2	7.4	1.6	0.2		
	410	0.6	0.1	0.1	0.1		
	440	1.8	0.5	0.1	0.1		
	450	14.0	3.8	0.5	0.1		
	500	53.4	19.1	1.8	0.6		
	550	64.3	27.4	2.1	0.9		
	570	107.7	48.3	3.6	1.6		
	600	383.6	184.4	12.7	6.1		
	610	67.9	33.3	2.2	1.1		
	800	348.4	217.7	11.5	7.2		
	1000	2.3	1.6	0.1	0.1		
	1040	964.3	693.1	31.9	22.9		
	1300	53.0	41.3	1.8	1.4		
	1500	155.6	126.0	5.1	4.2		
	1750	384.3	322.2	12.7	10.7		
TOTALS		3022.5	1729.6			14.3	8.2
5	250	5.4		0.1			
	260	6.6		0.1			
	310	3.2		0.1			
	320	8.7		0.1			
	330	67.6		0.7			
	340	142.2		1.4			
	350	18.5		0.2			
	400	287.2	44.9	2.8	0.4		
	410	66.7	12.1	0.7	0.1		
	430	214.6	49.1	2.1	0.5		
	450	352.2	95.2	3.4	0.9		
	460	34.1	9.9	0.3	0.1		
	480	285.7	92.9	2.8	0.9		
	490	48.9	16.7	0.5	0.2		
	500	278.4	99.4	2.7	1.0		
	510	848.6	315.6	8.3	3.1		
	550	105.5	44.9	1.0	0.4		
	570	49.0	22.0	0.5	0.2		
	590	130.2	61.3	1.3	0.6		
	600	3532.2	1698.2	34.6	16.6		
	640	99.7	51.6	1.0	0.5		
	750	648.5	387.2	6.3	3.8		
	840	253.0	163.1	2.5	1.6		

TABLE 33. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	870	155.1	102.1	1.5	1.0		
	900	1.9	1.3	0.1	0.1		
	950	378.6	261.1	3.7	2.6		
	1040	656.4	471.8	6.4	4.6		
	1050	1540.4	1111.6	15.1	10.9		
TOTALS		10219.0	5111.9			48.4	24.2
6	280	7.5		0.6			
	300	12.4		1.0			
	500	271.8	97.1	22.0	7.9		
	550	269.3	114.6	21.8	9.3		
	650	664.4	349.7	53.8	28.3		
	1000	8.7	6.1	0.7	0.5		
TOTALS		1234.1	567.5			5.8	2.7
7	250	80.7		22.0			
		285.8	77.2	78.0	21.1		
TOTALS		366.5	77.2			1.7	0.4
9	400	43.3	6.8	27.9	4.4		
	680	112.0	61.6	72.1	39.7		
TOTALS		155.3	68.4			0.7	0.3

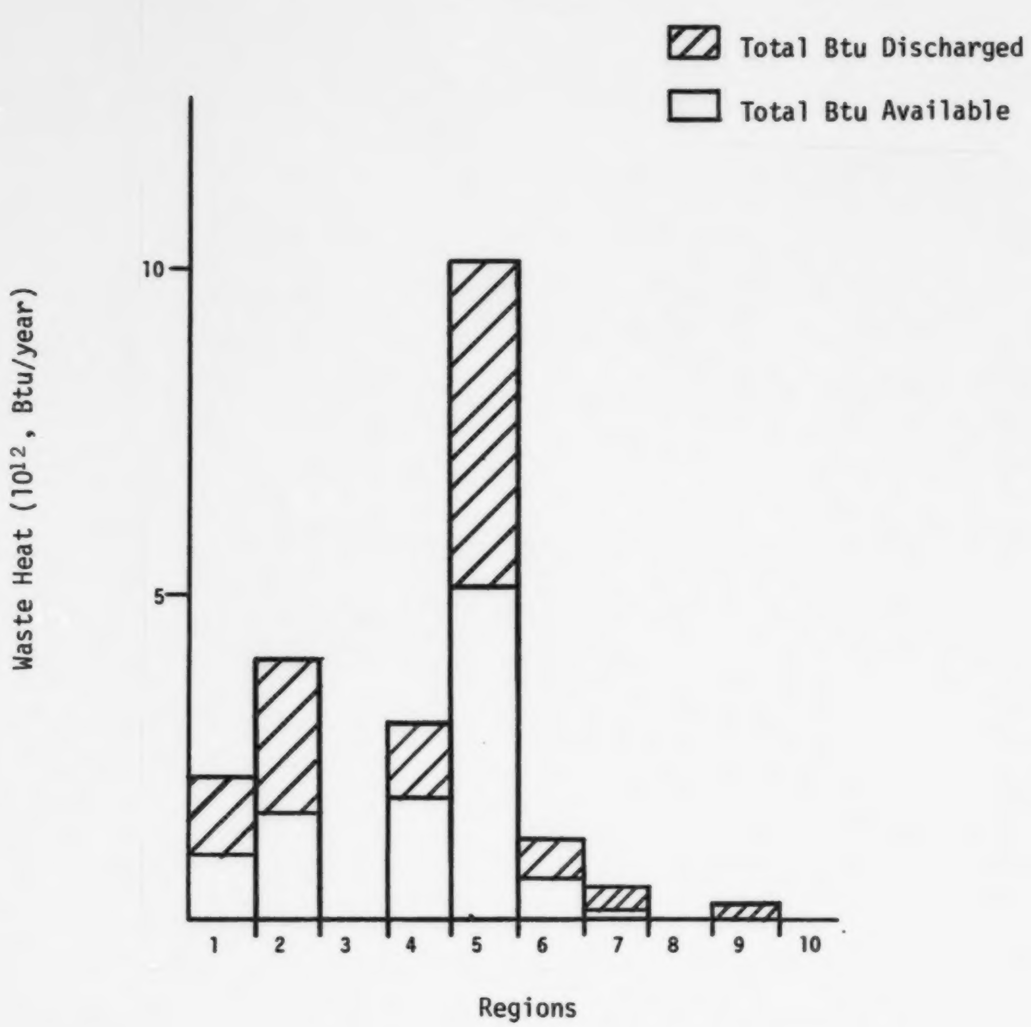

Figure 27. Regional totals for Pressed and Blown Glass (flue gases only) (SIC 3229), (1977).

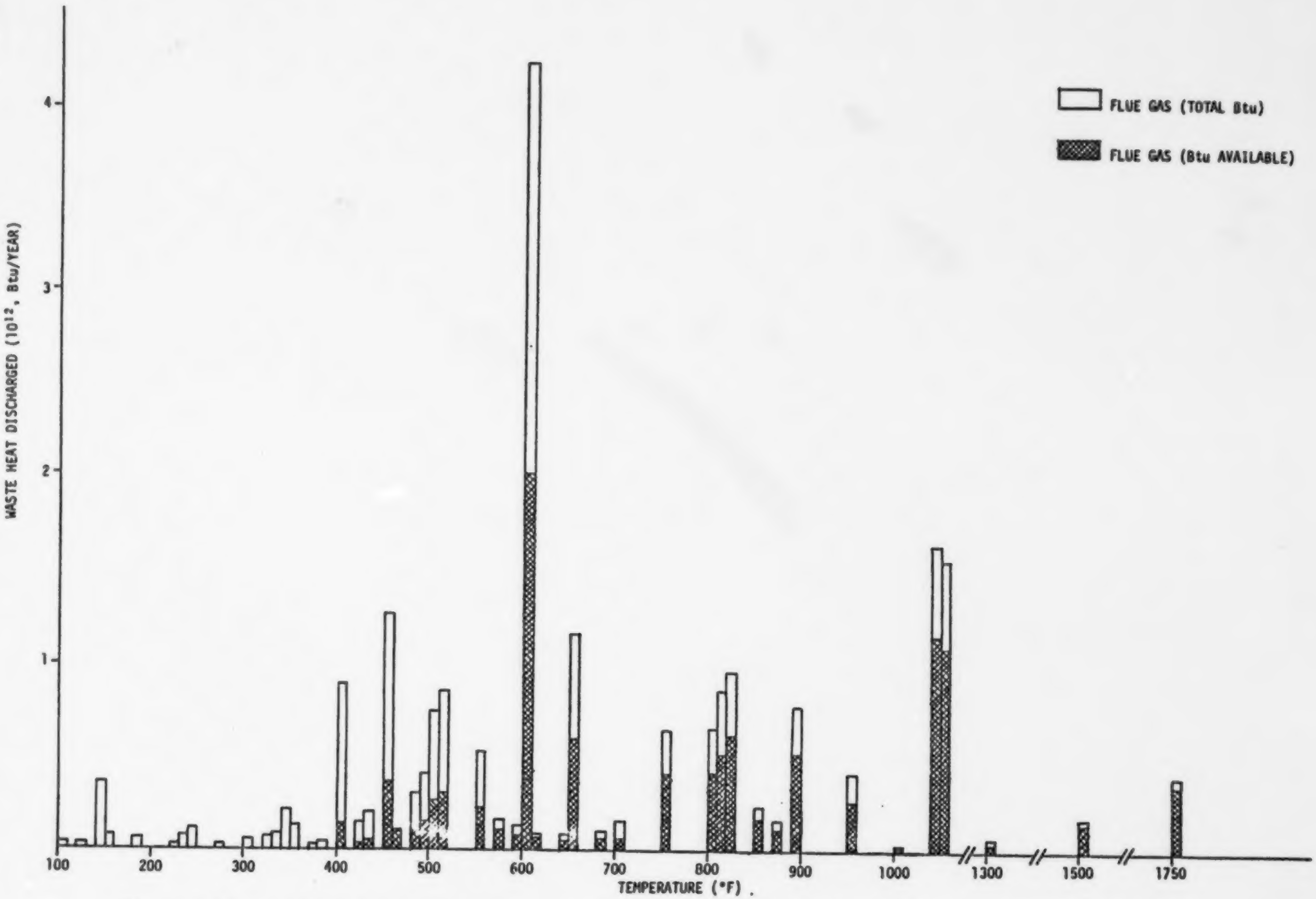

Figure 28. Waste heat temperature profile for Pressed and Blown Glass (SIC 3229), (flue gases only).

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LIME (SIC 3274)

Introduction

The products included in SIC 3274 are quicklime (CaO), hydrated Lime ($Ca(OH)_2$), and "deadburned" dolomite (CaMgO).

Lime is basically calcined limestone. Either plain or dolomitic limestone may be used. The former yields high calcium quicklime and the latter yields dolomitic quicklime. The two types are interchangeable in many uses but dolomitic quicklime is preferred for refractory use. Production of the two types of quicklime are essentially identical.

Limestone is mined or quarried and is transported to the mills where it is crushed and screened. After grading to size, the limestone is fed into refractory lined chambers and heated to a temperature of approximately 2000°F. Calcining, performed in rotary, vertical, or rotary hearth kilns, drives off the carbon dioxide from the limestone, leaving calcium oxide which is known as quicklime. Dolomitic quicklime will also contain varying amounts of magnesium oxide.

In 1971, a total of 19,591,000 short tons of lime were produced. Of this about 77% was quicklime, 18% hydrated lime, and 5% dolomite lime. Approximately 37% of this production was captive, (i.e., made and consumed in the same facility).

The four principal uses of lime sold by producers in 1971 were: chemical and industrial, 79%; construction, 15%; refractory, 5%; and agricultural, 1%. The leading individual uses were basic oxygen steel furnaces, alkalies, water purification, and refractory dolomite.

Geographical Distribution

Lime plants are generally located near large deposits of limestone. The major influence of plant location has been freight charges. To minimize operation costs, lime plants have located themselves in the immediate vicinity of limestone deposits.

Energy Consumption

Energy purchased by Lime industry, SIC 3274, in 1974, was nearly 98 trillion Btu. Roughly 98% of this energy consisted of purchased fuels. The largest portion of these fuels, 51% was furnished by coal, 38% came from natural gas, and 11% from fuel oils. Essentially all of this energy was for kiln fuel.

Energy consumption was estimated as 4.64 million Btu per ton of lime produced. Future energy consumption per ton of lime was expected to decrease despite pollution control regulations which should boost total energy consumption. One of the most important trends in the lime industry was the increasing demand for quicklime of higher purity. This single factor has initiated considerable research and development into new types of kilns, new methods of firing, and other refinements to existing vertical and rotary kilns. Since natural gas is the most suitable fuel for producing lime of higher purity, it is likely that relatively more gas will be used.

Point Sources Of Waste Heat

The major sources of waste heat within the lime industry are: stack gases from kilns; air cooling of calcined limestone; and non-contact cooling waters for tube mill and kiln bearings, hydrator pump pistons, and general grinding and equipment cooling.

Flow rates and differential temperatures of noncontact cooling water for plant equipment cooling accounted for anywhere from 100 to 400 gallons per ton of lime produced with differential temperatures from 5°F to 10°F. This corresponds to 5,000 to 30,000 Btu of heat rejected per ton of lime produced.

Discussion Tables and Graphs

Table 34 presents a summary of the total waste heat discharged by the Lime Industry and categorizes this discharge as a function of its reported point source. This table indicates that 60% of the purchased fuels and electric energy was discharged as waste heat. Essentially all of this was discharged as flue gases.

As was noted previously in the discussions, the most energy consuming operation in lime production is calcining. This process utilizes primarily all of the purchased fuels and discharges the largest quantity of waste heat. However, in Table 34, this is not obvious as calcining only shows 3.51% of the 60.39% waste heat from flue gases. The IPP codes established for SIC 3274 by the EPA list two calcining codes. IPP#3 represents verticle kilns and IPP#4 represents rotary kilns. A review of the data, however, indicates no calcining discharges for rotary kilns (the most common in use in lime products) and only reports a few verticle kiln discharges in EPA region 5 only. Because of this, it was suspected that the calcining flue gases were incorporated the flue gases from other working processes, except for those vertical kilns utilized in region 5. This may be because of kiln charge drying and preheating procedures practiced by this industry. Consequently, these gases were listed under their point of discharge, which if our assumption was correct, was the crushing mills.

A breakdown of the total waste heat discharged according to EPA region and discharge temperature is presented in Table 35. This indicates that EPA regions 5 and 6 together account for 74% of the total waste heat discharged. This data is further summarized in Figure 29.

The waste heat temperature profile for lime production is presented in Figure 30. The two most signifcant waste heat discharge temperatures were 200°F and 500°F. These two combined equal 29% of the total waste heat discharged.

TABLE 34. TOTAL WASTE HEAT DISCHARGED BY LIME (SIC 3274)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($x10^9$)	TOTAL Btu AVAILABLE ($x10^9$)	% Btu AVAILABLE	% WASTE① HEAT
	FLUE GASSES					
BL	Process, NEC	100-1500	17496.59	1189.40	6.80	14.30
1	Crushing, Primary	120-3000	39435.98	15822.15	40.12	32.22
2	Crushing, Secondary	140-900	10635.52	2094.45	19.69	8.69
3	Calcining	500	4291.60	1532.71	35.71	3.51
00	Combustion, NEC	120-600	2047.83	477.50	23.32	1.67
	TOTAL	100-3000	73907.98	21116.21	28.57	60.39
	WASTEWATER					
	Non-Contact Equip. Cooling	85-90	409,38			0.21
	TOTAL WASTEWATER	85-90	117-702			0.21
	TOTAL	85-3000	74317.36	21116.21	28.40	60.60

① Based on purchased fuel & electricity

TABLE 35. REGIONAL WASTE HEAT DISCHARGED BY LIME (FLUE GASES ONLY) (SIC 3274)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	200	42.7		5.2			
	210	362.8		44.3			
	250	10.5		1.3			
	400	403.6	63.1	49.2	7.7		
TOTALS		819.6	63.1			1.1	0.1
2	100	2.0		0.4			
	150	6.5		1.3			
	390	85.5	11.0	16.8	2.2		
	500	245.8	87.8	48.2	17.2		
	900	169.7	113.8	33.3	22.3		
TOTALS		509.5	212.6			0.7	0.3
3	120	72.1		2.6			
	130	123.8		4.4			
	140	190.8		6.8			
	150	532.2		19.2			
	160	6.5		0.2			
	180	22.1		0.8			
	190	287.8		10.3			
	200	88.4		3.2			
	300	205.1		7.3			
	320	198.2		7.1			
	440	47.1	11.8	1.7	0.4		
	460	31.5	9.1	1.1	0.3		
	470	46.1	14.2	1.7	0.5		
	480	59.4	19.3	2.1	0.7		
	550	109.1	46.4	3.9	1.7		
	1500	769.5	623.2	27.6	22.3		
TOTALS		2792.8	724.0			3.8	1.0
4	110	4.0		.1			
	120	65.2		1.0			
	150	43.7		0.7			
	200	196.8		3.1			
	250	83.1		1.3			
	280	408.5		6.5			
	350	55.6		0.9			
	420	2122.9	437.1	33.9	7.0		
	500	1180.2	421.5	18.9	6.7		
	600	2099.4	1006.9	33.5	16.1		
TOTALS		6254.5	1865.5			8.5	2.5

(continued)

TABLE 35. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5	100	0.6		0.1			
	120	84.1		0.3			
	130	19.5		0.1			
	140	98.6		0.3			
	160	375.1		1.3			
	200	55.4		0.2			
	210	36.4		0.1			
	250	98.3		0.3			
	270	599.2		2.0			
	300	1734.5		5.9			
	350	2122.5		7.3			
	400	566.2	88.4	1.9	0.3		
	500	5624.8	2008.9	19.2	6.9		
	550	5103.6	2171.8	17.4	7.4		
	670	650.8	292.2	2.2	1.0		
	600	2129.8	1023.9	7.3	3.5		
	670	1792.4	972.2	6.1	3.3		
	700	361.7	204.2	1.2	0.7		
	1000	2609.8	1843.9	8.9	6.3		
	1100	1045.7	768.9	3.6	2.6		
	1800	4141.1	3491.1	14.2	11.9		
TOTALS		29249.9	12865.4			39.5	17.4
6	110	7.5		0.1			
	120	16.1		0.1			
	130	45.5		0.2			
	140	275.8		1.1			
	150	1598.9		6.3			
	160	205.7		0.8			
	170	97.6		0.4			
	180	41.3		0.2			
	190	27.2		0.1			
	200	12618.1		49.7			
	240	6.7		0.1			
	300	128.9		0.5			
	330	4194.9		16.5			
	380	330.8	33.1	1.3	0.1		
	410	637.4	115.9	2.5	0.5		
	420	383.8	79.0	1.5	0.3		
	430	398.1	91.0	1.6	0.4		
	450	687.9	185.9	2.7	0.7		
	460	872.1	252.4	3.4	1.0		
	500	38.8	13.9	0.2	0.1		
	1100	2800.7	2059.3	11.0	8.1		
TOTALS		25408.0	2830.5			34.4	3.8

TABLE 35. (continued)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
7	180	25.5		1.0			
	210	205.1		7.9			
	300	217.9		8.4			
	420	8.4	1.7	0.3	0.1		
	460	1295.9	375.1	50.1	14.5		
	520	324.2	125.2	12.5	4.8		
	530	509.5	203.8	19.7	7.9		
TOTALS		2586.5	705.9			3.5	1.0
8	300	0.9		.5			
	500	188.7	67.4	99.5	35.5		
TOTALS		189.6	67.4			0.3	0.1
9	130	10.9		0.2			
	180	3.6		0.1			
	270	295.1		5.6			
	300	598.0		11.3			
	320	419.4		7.9			
	350	424.5		8.0			
	360	388.6	13.8	7.4	0.3		
	400	232.5	36.3	4.4	0.7		
	440	1153.1	288.3	21.8	5.5		
	500	954.1	340.7	18.1	6.4		
	600	802.7	385.9	15.2	7.3		
TOTALS		5284.4	1065.1			7.1	1.4
10	100	0.2		0.1			
	150	2.5		0.3			
	350	22.2		2.7			
	3000	789.7	716.7	96.9	88.0		
TOTALS		814.6	716.7			1.1	1.0

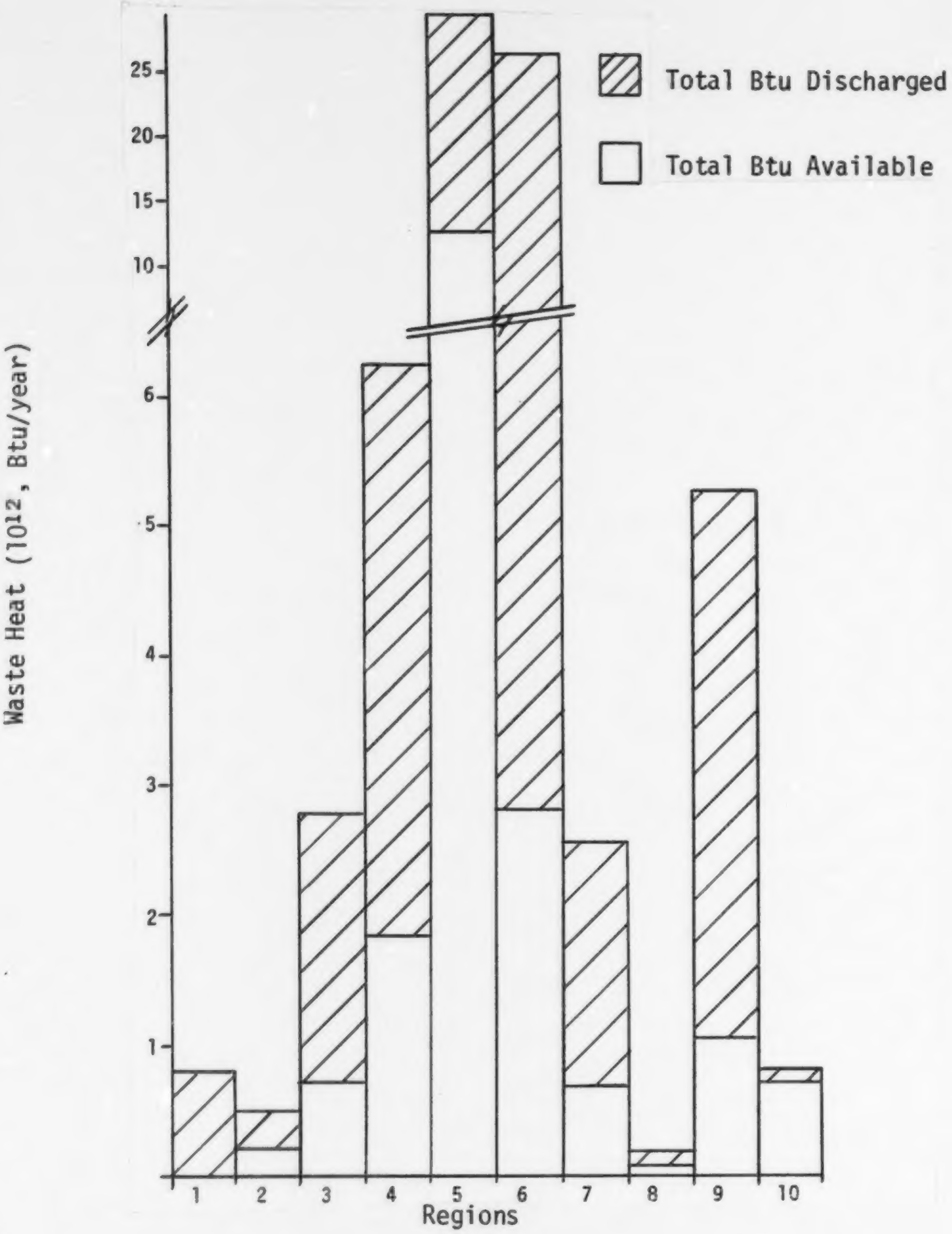

Figure 29. Regional totals for Lime (SIC 3274), (1977).

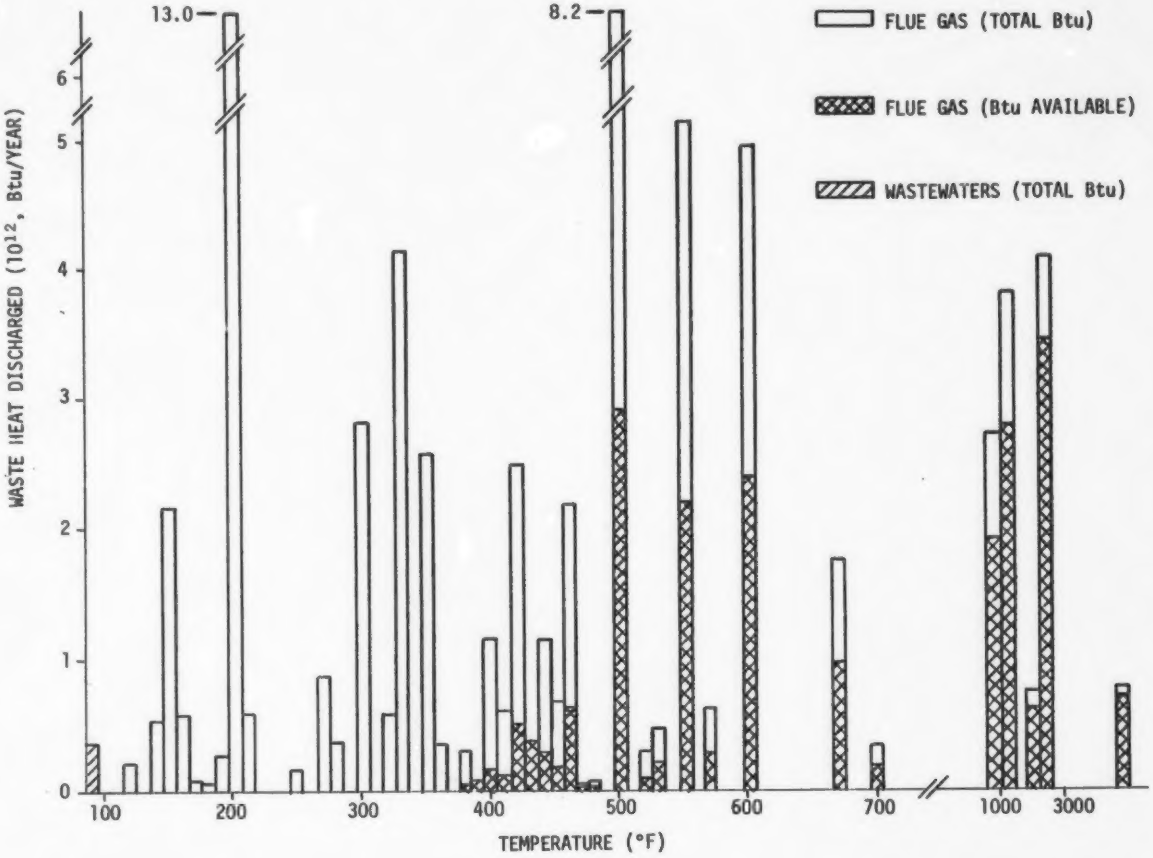

Figure 30. Waste heat temperature profile for Lime (SIC 3274).

HYDRAULIC CEMENT INDUSTRY (SIC 3241)

Introduction

The Hydraulic Cement industry, SIC 3241, is defined as that group of establishments primarily engaged in the manufacturing of hydraulic cement. This includes portland, natural, masonry, and pozzolan cements. In the United States over 90% wt of the industry's production of hydraulic cement is in the form of portland cement.

Cement is manufactured by a continuous process, normally interrupted only to reline the kilns. Essentially, the production of hydraulic cement involves 1) proportioning a lime-containing substance and materials containing silica, aluminum, and iron; 2) grinding these to a slurry or powder; 3) "burning" the mixture in a rotary kiln until fused; and 4) grinding the "clinker" that comes out of the kiln with gypsum into a fine powder.

The ordinary ingredients for the production of cement include lime (calcium oxide), silica, alumina, and iron. Lime, which constitutes the largest single ingredient, is most commonly obtained from limestone, cement rock, oyster shell marl, or chalk. All of which are principally calcium carbonate.

Two types of processes are used in the manufacture of cement, "wet" and "dry". At wet plants, the raw materials are ground with water and fed to the kiln in a slurry. At dry plants the raw materials are dried before grinding, and then fed to the kiln in a dry state. Although the wet process kiln has a higher heat requirement than the dry process kiln, the fuel consumption difference (in many cases) is partially offset by the heat consumed in those dry process plants in which the dryers precede the raw materials grinding. The moisture content of the raw materials available at a given location frequently determines which process a plant will use. For example, if clay and marl with a high water content are available, the wet process may prove more economical.

Geographical Distribution

In 1974, 53 companies in 41 states and Puerto Rico produced more than 79 million short tons of cement. The number of plants in operation has declined from a high of 188 in 1967 to an estimated 168 plants operating in 1977. The annual capacity of these plants range from 0.2 to 3.8 million tons.

In general, cement companies market locally, where they may compete with as many as 15 to 20 other companies. Currently, all but 10 states have one or more cement plants. Since cement has a high weight-to-value ratio, it is generally transported on land by rail or truck over a radius of 200 to 300 miles.

Energy Consumption

In 1974, the United States hydraulic cement industry consumed more than 490 trillion Btu of fossil fuels and about 11 billion Kwh of electricity. To produce one ton of cement, the average cement plant used 6.7 million Btu of energy of which 93% was from fossil fuel and 7% from electricity. The cost of this energy represented about 40% of the production costs.

The cement industry uses all forms of energy, coal, fuel oils, natural gas, and electricity. The consumption of coal and natural gas is about equal.

Of all processes, the one using a preheater for raw material preheating, consumes the least energy. For all processes the clinkering step consumes the most energy, with an average of 80% of the total energy used, most of which is fossil fuel. Most of the consumed electricity is used in grinding.

Energy consumption in clinkering varies according to type of kiln. In 1974 the wet process consumed 61.3% of the total energy consumed in cement manufacture, yet it contributed only 57.9% of the total clinker produced. The dry process, on the other hand, consumed 38.7% of the total energy to produce 42.1% of the total clinker.

The trends in unit energy use for the wet and dry processes are more dramatic. In 1950, unit energy consumption for the two processes was within 1%. This is 8.44 x 10^6Btu/ton cement produced for the wet process versus 8.34 x 10^6Btu/ton cement for the dry process. By 1974, the spread in values increased to 13% with the wet process at 7.41 x 10^6Btu/ton and the dry process 6.20 x 10^6Btu/ton.

Point Source Of Waste Heat

The major sources of waste heat in cement manufacturing are: stack gases from the kiln; clinker cooler and dryer (in the dry process), and non-cooling waters.

In the production of portland cement, the major use of water is for cooling. This water has two main purposes, equipment cooling and cement cooling. Equipment cooling includes bearings on the kiln and grinding equipment, air compressors, and burner pipes. Cement cooling removes the heat generated by finished grinding prior to storage or shipment. It has been estimated that the average non-contact cooling water requirements for cement production are:

	Gallons/Ton	Differential Temperature	Waste Heat per Ton of Cement
Equipment Cooling	400	5°F	16,690 Btu/ton
Cement Cooling	200	25°F	41,725 Btu/ton

As compared to kiln radiation and convection losses, (estimated to be about 17% of the total fuel input) heat rejection by non-contact cooling water (roughly 1%) can be considered insignificant.

Discussion - Tables and Graphs

A summary of the waste heat discharged by the lime production is presented in Table 36. This table indicates that about 68% of the industry's purchased fuels and electricity were discharged as waste heat to the environment. Almost all of which was discharged by flue gases.

As was stated in the previous discussions, clinking kilns consume the almost 80% of the total energy consumed. However, a review of Table 36 indicates that quarrying, generally is the largest waste heat discharging process. This is due to the fact that clinking kilns in SIC 3241 were not assigned an IPP number by the EPA. Therefore, it is suspected that the kiln and flue gases were included with other IPP numbers.

Table 37 differentiates the waste heat discharges according to their EPA region and discharge temperature. This indicates that these discharges are fairly evenly distributed throughout the EPA regions, with the exception of EPA region. 1. This data is further summarized in Figure 31.

The waste heat temperature profile for Cement (SIC 3241) is presented in Figure 32. This indicates that the majority of waste heat discharged is discharged at temperatures between 400°F and 600°F. This temperature range accounts for 60% of the total waste heat discharged by the Cement Industry.

TABLE 36. TOTAL WASTE HEAT DISCHARGED BY HYDRAULIC CEMENT (SIC 3241)

② IPP #	DESCRIPTION	TEMPERATURE RANGE (°F)	TOTAL Btu ($x10^9$)	TOTAL Btu Available ($x10^9$)	% Btu AVAILABLE	% WASTE HEAT ①
	FLUE GASSES					
BL	Process, NEC	100-1200	33357.88	7670.99	22.99	6.63
1	Quarrying, General	100-1200	148296.24	47244.05	31.86	29.48
3	Secondary Crushing	110-300	195.52	0.00	0.00	0.04
10	Combustion, Coal	500	3133.26	1119.02	35.71	0.22
00	Combustion, NEC	150-550	14052.19	4284.01	30.49	2.79
2	Primary Crushing	100-650	141640.20	28132.84	19.86	28.15
	FLUE TOTAL	100-1200	310,675.29	88450.91	25.96	67.31
	WASTEWATER					
	Non-Contact Equip. Cooling	85	1428.20			0.32
	Non-Contact Cement Cooling	105	3570.50			0.80
	TOTAL WASTEWATER	85-105	4998.70			1.12
	TOTAL	85-1200	345673.99	88450.91	25.59	68.43

① Based on purchased fuel & electricity

② NEDS data, EPA/2-76-005 OAQPS guidelines

TABLE 37. REGIONAL WASTE HEAT DISCHARGED BY HYDRAULIC CEMENT (SIC 3241)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	90	4.8		0.4			
	110	12.0		1.0			
	300	13.7		1.2			
	310	265.7		23.1			
	330	613.5		53.4			
	400	255.2	39.9	22.2	3.5		
TOTALS		1148.1	39.9			0.3	0.1
2	90	142.9		0.4			
	100	86.4		0.3			
	110	360.5		1.1			
	120	113.7		0.3			
	140	5.7		<0.1			
	150	207.0		0.6			
	170	222.2		0.7			
	180	134.5		0.4			
	200	589.5		1.7			
	210	535.3		1.6			
	250	528.5		1.0			
	260	84.6		0.2			
	270	128.7		0.4			
	300	32.5		0.1			
	320	1160.0		3.4			
	340	15.5		<0.1			
	350	76.8		0.2			
	370	236.7	16.3	0.7	<0.1		
	400	3009.5	470.2	8.8	1.4		
	450	1384.7	374.2	4.1	1.1		
	460	682.9	197.7	2.0	0.6		
	470	7800.4	2400.1	22.9	7.0		
	480	1846.8	600.2	5.4	1.8		
	500	12555.1	4484.0	36.8	13.1		
	520	1556.8	601.5	4.6	1.8		
	560	1265.9	533.8	3.7	1.6		
	1200	40.7	30.9	0.1	0.1		
TOTALS		34103.6	9729.0			10.0	2.9
3	90	298.0		0.4			
	100	102.0		0.1			
	110	748.4		1.1			
	120	5.4		<0.1			
	130	28.2		<0.1			
	150	328.7		0.5			
	160	261.7		0.4			
	170	816.4		1.1			

(continued)

TABLE 37. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
3(Cont.)	180	307.0		0.4			
	190	47.8		0.1			
	200	73.6		0.1			
	220	71.2		0.1			
	250	1285.3		1.8			
	260	521.0		0.7			
	270	834.5		1.2			
	280	6.7		0.1			
	300	761.0		1.1			
	320	231.6		0.3			
	350	2269.5		3.2			
	370	158.7	10.9	0.2	0.1		
	400	4700.6	734.5	6.6	1.0		
	450	6928.2	1872.5	9.7	2.6		
	460	3668.0	1061.8	5.2	1.5		
	470	4075.0	1253.9	5.7	1.8		
	490	1939.5	662.3	2.7	0.9		
	500	18252.7	6518.8	25.7	9.2		
	510	3639.6	1354.3	5.1	1.9		
	540	1217.0	502.7	1.7	0.7		
	550	6006.0	2555.7	8.4	3.6		
	600	6569.0	3158.2	9.2	4.4		
	650	6018.9	3167.8	8.5	4.5		
TOTALS		71111.0	22853.3			20.9	6.7
4	90	198.0		0.4			
	100	4.9		0.1			
	110	502.8		1.1			
	120	43.7		0.1			
	130	12.7		0.1			
	140	129.2		0.3			
	150	215.7		0.5			
	180	231.3		0.5			
	190	1.4		0.1			
	200	520.9		1.1			
	210	149.1		0.3			
	220	48.9		0.1			
	230	431.6		0.9			
	240	39.0		0.1			
	250	1061.4		2.2			
	260	574.5		1.2			
	270	1075.4		2.3			
	280	78.0		0.2			
	290	758.1		1.5			
	300	3124.8		6.6			
	310	1273.6		2.7			
	320	1182.3		2.5			

TABLE 37. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont)	330	830.0		1.8			
	340	686.7		1.5			
	350	6263.6		13.2			
	370	1007.9	69.5	2.1	0.1		
	380	2455.5	245.6	5.2	0.5		
	390	2060.2	265.8	4.4	0.6		
	400	1267.8	198.1	2.7	0.4		
	450	4704.2	1271.4	9.9	2.7		
	500	3795.6	1355.6	8.0	2.9		
	550	2012.3	856.3	4.3	1.8		
	560	409.6	179.2	0.9	0.4		
	570	442.0	198.5	0.9	0.4		
	600	1017.1	489.0	2.2	1.0		
	610	741.5	363.8	1.6	0.8		
	700	8507.5	4802.6	18.0	10.2		
TOTALS		47278.4	10295.3			13.9	3.0
5	90	152.0		0.4			
	100	1.5		0.1			
	110	388.9		1.1			
	120	5.7		0.1			
	150	1.8		0.1			
	160	44.4		0.1			
	170	289.6		0.8			
	180	9.3		0.1			
	190	220.3		0.6			
	200	116.5		0.3			
	220	375.8		1.0			
	240	121.9		0.3			
	250	58.6		0.2			
	260	374.6		1.0			
	270	168.8		0.5			
	280	1127.1		3.1			
	290	255.9		0.7			
	300	186.1		0.5			
	320	1483.0		4.1			
	340	803.6		2.2			
	350	2644.8		7.3			
	360	6562.2	234.4	18.1	0.6		
	370	1051.5	72.5	2.9	0.2		
	400	5740.0	896.9	15.8	2.5		
	460	946.1	273.9	2.6	0.8		
	480	1022.2	332.2	2.8	0.9		
	500	1363.5	487.0	3.8	1.3		
	510	1972.3	733.9	5.4	2.0		
	530	1683.4	673.4	4.6	1.9		

TABLE 37. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	550	1630.0	693.6	4.5	1.9		
	580	1454.6	669.1	4.0	1.8		
	600	1674.4	805.0	4.6	2.2		
	700	896.7	506.2	2.5	1.4		
	1200	2055.1	1559.7	5.7	4.3		
TOTALS		36349.4	7937.6			10.7	2.3
6	90	247.5		0.4			
	110	619.9		1.0			
	140	156.0		0.3			
	150	1126.0		1.9			
	160	38.8		0.1			
	170	50.8		0.1			
	180	31.5		0.1			
	200	31.5		0.1			
	200	1044.3		1.8			
	210	659.0		1.1			
	260	501.8		0.8			
	270	142.9		0.2			
	300	235.2		0.4			
	320	3550.5		6.0			
	330	674.2		1.1			
	340	395.4		0.7			
	350	1227.9		2.1			
	360	591.0	21.1	1.0	0.1		
	370	838.4	57.8	1.4	0.1		
	380	1129.9	113.0	1.9	0.2		
	400	4219.0	659.2	7.1	1.1		
	420	2159.8	444.7	3.7	0.8		
	440	4400.3	1100.1	7.5	1.9		
	450	8064.1	2179.5	13.7	3.7		
	470	2725.2	838.5	4.6	1.4		
	480	103.6	33.7	0.2	0.1		
	500	3349.7	1196.3	5.7	2.0		
	510	4811.3	1790.3	8.1	3.0		
	520	2030.5	784.5	3.4	1.3		
	570	2334.6	1048.2	4.0	1.8		
	580	3155.4	1451.5	5.3	2.5		
	590	42.4	19.9	0.1	0.1		
	610	187.6	92.0	0.3	0.2		
	670	2502.2	1357.1	4.2	2.3		
	680	2704.4	1487.4	4.6	2.5		
	700	2157.7	1218.1	3.7	2.1		
	810	606.4	382.1	1.0	0.6		

TABLE 37. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6 (Cont)	820	594.3	377.5	1.0	0.6		
	830	517.0	330.9	0.9	0.6		
TOTALS		59060.1	16983.3			17.3	5.0
7	90	135.6		0.4			
	100	1.2		0.1			
	110	339.1		1.0			
	150	70.3		0.2			
	170	17.6		0.1			
	180	72.4		0.2			
	200	241.6		0.7			
	220	725.2		2.2			
	230	191.7		0.6			
	250	678.6		2.1			
	260	103.6		0.3			
	270	866.7		2.7			
	290	681.0		2.1			
	300	642.1		2.0			
	330	135.7		0.4			
	340	584.0		1.8			
	370	779.4	53.8	2.4	0.2		
	400	5292.9	827.0	16.4	2.6		
	410	7687.5	1397.7	23.8	4.3		
	420	231.4	47.6	0.7	0.1		
	450	8590.8	2321.8	26.5	7.2		
	530	1075.8	430.3	3.3	1.3		
	600	2215.3	1065.0	6.8	3.3		
	650	1476.2	776.9	4.6	2.4		
TOTALS		32360.8	6920.2			9.5	2.0
8	90	56.0		0.4			
	110	139.9		1.0			
	140	4.9		0.1			
	150	<0.1		<0.1			
	270	1360.7		10.2			
	290	457.9		3.4			
	300	240.6		1.8			
	350	359.6		2.7			
	380	440.2	44.0	3.3	0.3		
	460	892.2	258.3	6.7	1.9		
	470	986.1	303.4	7.4	2.3		
	500	8025.4	2866.2	60.0	21.4		
	600	599.6	288.3	4.5	2.2		
TOTALS		13367.2	3760.2			3.9	1.1

TABLE 37. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
9	90	117.3		0.4			
	100	56.9		0.2			
	110	293.5		1.0			
	150	44.1		0.2			
	170	22.3		0.1			
	180	441.3		1.6			
	190	66.0		0.2			
	200	329.4		1.2			
	210	176.5		0.6			
	230	122.2		0.4			
	240	39.0		0.1			
	250	183.1		0.7			
	260	37.0		0.1			
	270	726.6		2.6			
	280	329.0		1.2			
	290	724.7		2.6			
	310	461.3		1.6			
	320	1323.7		4.7			
	340	670.9		2.4			
	360	1829.0		6.5			
	380	105.6	10.6	0.4	0.1		
	390	1657.3	213.9	5.9	0.8		
	400	1507.1	235.5	5.4	0.8		
	410	11055.1	2010.0	39.5	7.2		
	500	592.8	211.7	2.1	0.8		
	550	5497.2	2339.2	19.6	8.4		
TOTALS		27998.2	5086.2			8.2	1.5
10	90	75.0		0.4			
	110	4172.6		23.3			
	130	115.9		0.6			
	200	81.3		0.5			
	300	6.2		0.1			
	310	1024.8		5.7			
	330	258.4		1.4			
	420	751.4	154.7	4.2	0.9		
	450	974.3	263.3	5.4	1.5		
	510	5154.9	1918.1	28.8	10.7		
	550	2843.0	1209.8	15.9	6.8		
	600	2703.9	1300.0	15.1	7.3		
TOTALS		17899.1	4845.8			5.3	1.4

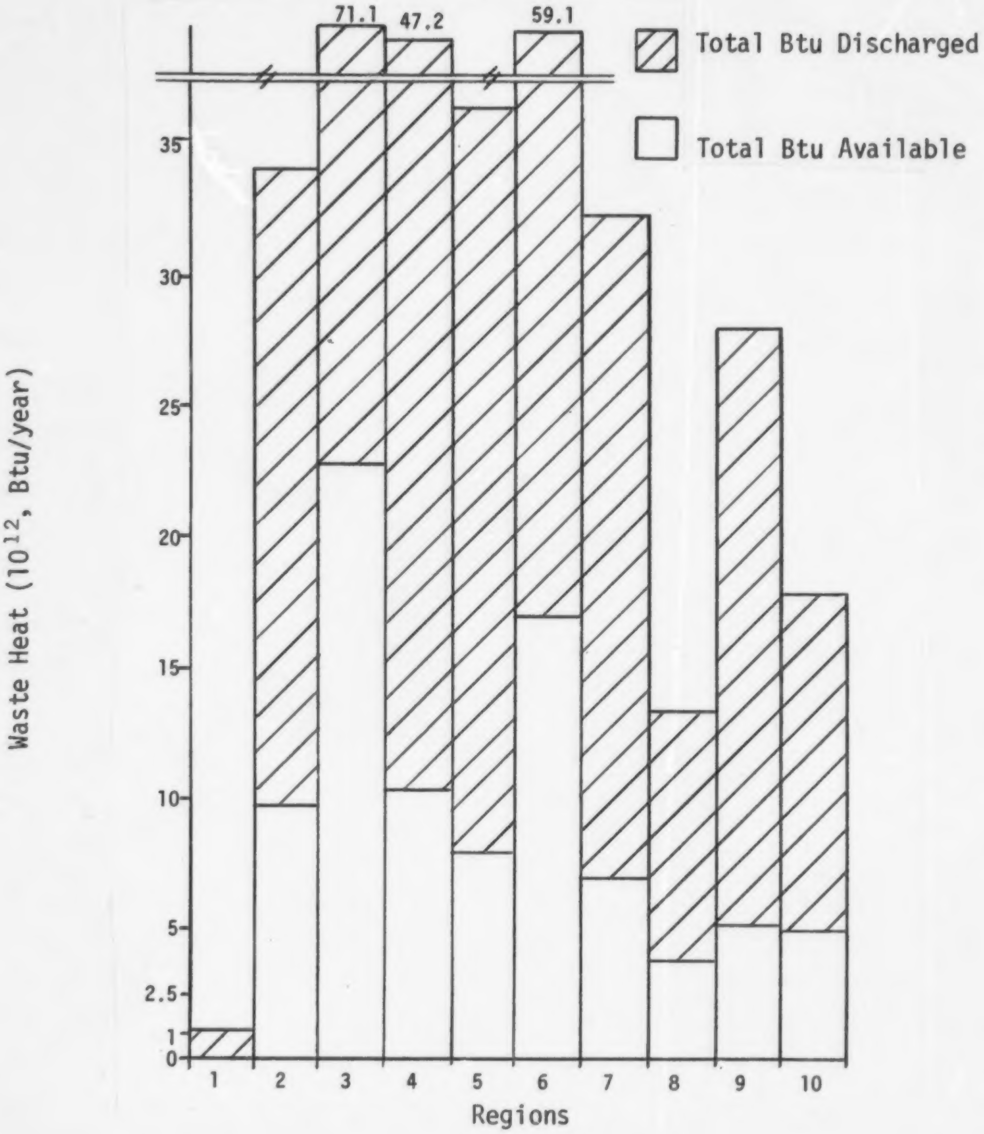

Figure 31. Regional totals for Hydraulic Cement (SIC 3241), (1977).

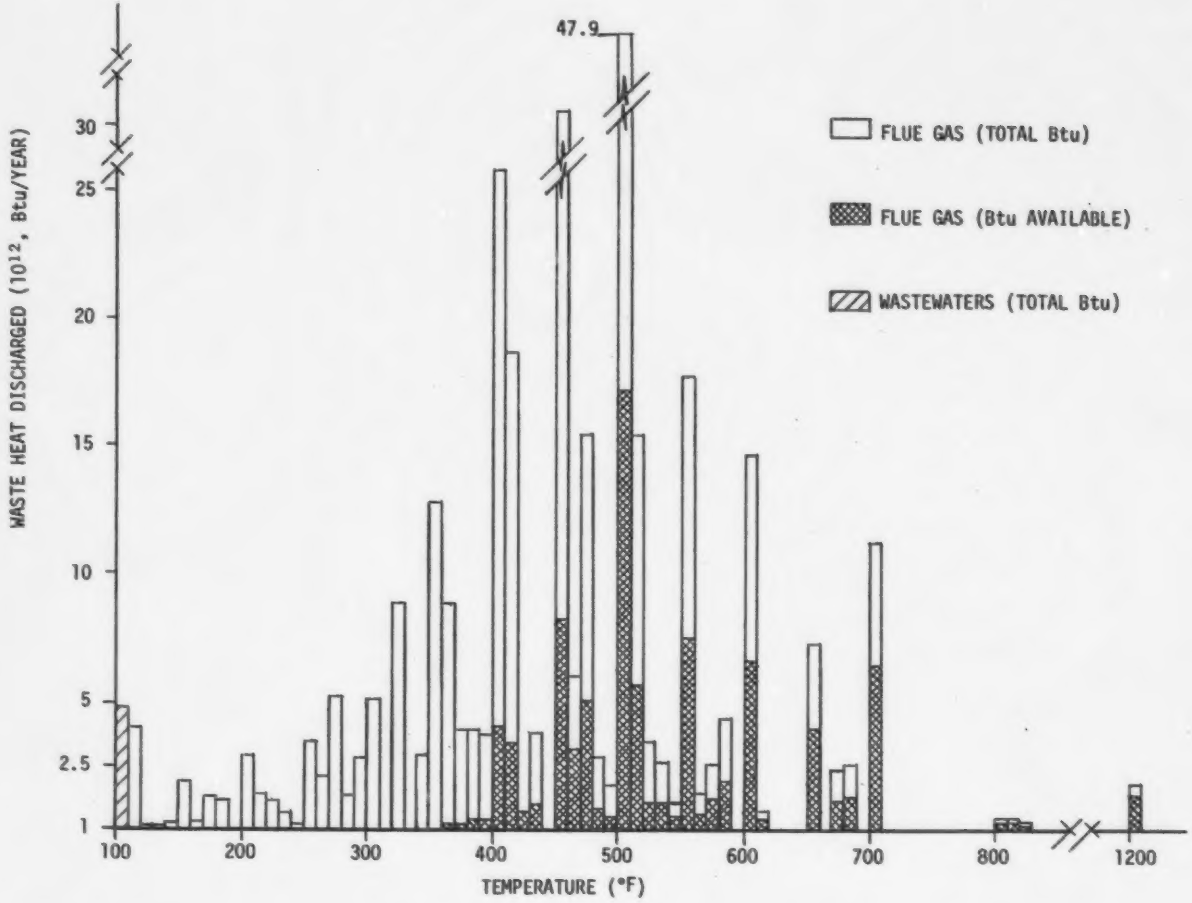

Figure 32. Waste heat temperature profile for Hydraulic Cement (SIC 3241).

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SECTION 7

CHEMICALS, ALLIED PRODUCTS (SIC 28)

INTRODUCTION

Chemicals and Allied Products (SIC 28) is the largest consumer group of purchased fuels and electricity within the 2-digit Standard Industrial Classifications as established by the United States Bureau of Census. This section of this report discusses the waste heat discharged from the six most energy intensive 4-digit SICs within this 2-digit classification. These industries are:

SIC#	Description
2812	Alkalies and Chlorine
2813	Industrial Gases
2819	Industrial Inorganic Chemicals
2865	Cyclic Crudes and Intermediates
2869	Industrial Organic Chemicals
2873	Nitrogenous Fertilizers

ALKALIES AND CHLORINE (SIC 2812)

Introduction

The Alkalies and Chlorine Industry are defined as those establishments involved in the production and sale of chlorine, caustic soda, and soda ash.

Chlorine and Caustic Soda

About 95% of the total annual production of chlorine and nearly all of the production of caustic soda is produced by the electrolysis of brine solutions with the subsequent evolution of hydrogen gas as a byproduct.

There are two types of electrolytic cells which are presently in use. The diaphragm cell, which accounts for about 75% of the total annual production, and mercury cathode cells, which account for the remainder. The mercury cathode cells are slowly being phased out of use due to their greater energy requirements and their greater potential for adverse environmental impact.

Regardless of the specific type of cells used, the processes are essentially the same in respect to the nature of waste heat discharged to the environment and consequently this discussion is based on the processes using the diaphragm cell.

Geographic Distribution

Due to the fact that chlorine and caustic soda are low-cost, high tonnage commodities, these plants tend to be located near their market. Consequently, these plants are fairly evenly distributed throughout the United States with a heavy concentration of plants located in Texas and the Louisiana Gulf Coast. These areas account for about 60% of the United States chlorine production. Almost two thirds of the total annual production may be considered captive.

Energy Consumption

Electrical consumption for the production of one ton of chlorine consists of about 300 Kwh for cell electrolysis and about 250 Kwh for chlorine liquefication. Assuming a 32.5% efficiency in power generation, a total of 34.12×10^6Btu of fuel energy are required to generate the electricity to produce one ton of chlorine.

Fossil fuels, or hydrogen produced as a byproduct, are required for the production of steam. Caustic evaporation requires about 7 million Btu of steam per ton of chlorine produced. Utilizing an average boiler efficiency to 85%, 9.14×10^6Btu of fuel are required to produce this steam. This results in a total of 43.26×10^6Btu of energy consumed per ton of chlorine produced.

Point Sources of Waste Heat in Chloralkali Production

The largest waste heat stream discharged to the environment by chloralkali plants is the water vapor evaporated from the cell liquor during the concentration of the caustic soda solution to a 50% sodium hydroxide solution. About 4,700 pounds of water vapor are discharged from the evaporators per ton of chlorine produced. This stream exits the last effect with a differential temperature of about 40°F and at 1.7 psia. The Btu discharged by this stream is incorporated in Table 38, under Process NEC, with all other noncombustion offgases, except conveying. All combustion offgases, coal or otherwise, are also included in Table 38.

Sodium Carbonate

Sodium Carbonate is most commonly produced from trona, natural sodium sesquicarbonate ($Na_2CO_3NaHCO_3 \cdot 2H_2O$). In the monhydrate process, the ore is crushed and then calcined to produce a crude soda ash which is much more soluble than raw trona. The sesquicarbonate decomposes completely to Na_2CO_3at a calciner temperature of 300°F to 400°F. After calcination, the crude soda ash is leached with water and the extract is settled, clarified, and filtered. The clear carbonate liquor is then evaporated to produce crystalline sodium carbonate monohydrate. This crystallization is done in a series of three evaporators at about 100°C. These crystals are then calcined to soda ash (anhydrous sodium carbonate).

Enduse markets for soda ash are glass, 55%; chemicals, 25%, pulping, 6% detergents and soaps, 5%; water treatment, 3%; and others, 6%.

Geographical Distribution

Trona is mined in the Green River Basin in Wyoming, where the ore is about 95% sodium sesquicarbonate. There are four major producers of soda ash located there. Using a different process, natural soda ash is also produced from brine contained in dry, saline lakes, notably Searles Lake and Owens Lake in California. Energy costs and environmental regulations have forced the closing of many Solvay plants used to manufacture synthetic soda ash.

Energy Consumption

The most energy-intensive process steps in the production of soda ash by the monohydrate process are the calcination of the raw trona, evaporation, and product drying. In the Green River basin the main process fuel used is coal. This is used to fire the boiler and ore calciner. Steam is used for evaporation and product drying. Energy consumed in soda ash production is in the neighborhood of 7 million Btu per ton. Approximately 7.4 million tons of soda ash were produced in the United States in 1976 and production growth was expected to be 2.5 to 3.0% annually through 1980. Using these figures, the 1977 production was estimated to be 7.7 million tons.

Point Source of Waste Heat in Soda Ash Production

Five rejected heat streams have been identified in the production of soda ash by the monohydrate process. Of the streams identified, only one is in the form of wastewater. This is the condensate from the evaporator. This stream releases about 156,000 Btu of waste heat for every ton of soda ash produced. Other waste heat streams are summarized below:

Source	Type	Temperature (°F)	Cu.ft./Ton
Trona Calcination	Flue Gas	405	150,000
Boiler	Stack Gas	370	155,000
Monohydrate Drying	Air & Water Vapor	185	35,900
Soda Ash Cooling	Radiant Heat	300	-

All these rejected heat streams, except the evaporator condensate water, are included in Table 37 and are combined with the gaseous effluents from chloralkali plants and all other industries in SIC 2812. Any coal combustion flue gases are listed as such with all other combustion processes listed under combustion, NEC. Any noncombustion offgases are listed under process, NEC, except conveying.

Discussion - Tables and Graphs

The total waste heat discharged by the Alkalies and Chlorine Industry (SIC 2812) is presented in Table 38. This table differentiates the various flue gas discharges according to the process identifications (IPP#) established by the EPA's Office of Air and Waste Managements Office of Air Quality Planning and Standards (OAQPS). This table indicates that in 1977 the chloralkali industry discharged about 12% of its purchased fuels and electricity as waste heat. Almost 20% of this waste heat energy was discharged at temperatures greater than 350°F.

A regional breakdown of these waste heat discharges is presented in Table 39. This table indicates that EPA regions 5 and 6 have the greatest concentrations of waste heat discharges by chloralkali industry. Together these two regions account for almost 70% of the total waste heat discharged. This data is further summarized in Figure 33.

The waste heat temperature profile for the chlorine and alkali industry is presented in Figure 34. This figure indicates that waste heat discharged at 470°F accounts for 25% of the total waste heat discharged and 40% of the waste heat discharged as Btu Available. It should also be noted that all discharges at 470°F were discharged in EPA region 5.

TABLE 38. TOTAL WASTE HEAT DISCHARGED BY ALKALIES AND CHLORINE (2812)

② IPP #	DESCRIPTION	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	% Btu Available	%Waste ① Heat
	Flue Gases					
BL	Process, NEC	100-1500	9095.33	1031.99	11.35	4.68
1	Conveying	100-860	5676.90	041.41	16.58	2.92
50	Combustion, Coal	320	866.40	510.60	58.93	0.45
60	Combustion, Coal	470	1338.27	0.00	0.00	0.69
70	Combustion, Coal	500	5773.12	1776.34	30.77	2.97
00	Combustion, NEC	100-900	411.24	146.87	35.71	0.21
	Total Flue Gases	100-1500	23161.26	4407.21	19.03	11.93

1. Based on purchased fuels & electricity

2. NEDS data, 450/2-76-005 OAQPS guidelines

TABLE 39. REGIONAL WASTE HEAT DISCHARGED BY ALKALIES AND CHLORINE (SIC 2812)

EPA	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	19.6		0.6			
	110	9.3		0.3			
	120	4.3		0.1			
	130	5.5		0.2			
	140	34.8		1.0			
	150	19.8		0.6			
	160	3.4		0.1			
	170	65.0		1.9			
	190	0.4		0.1			
	230	0.1		0.1			
	300	74.7		2.2			
	310	19.4		0.6			
	320	53.0		1.6			
	350	27.0		0.8			
	390	3062.9	395.2	90.1	11.6		
TOTALS		3391.1	395.2			14.7	1.7
3	180	65.4		2.8			
	220	41.4		1.8			
	320	16.8		0.7			
	330	1196.2		51.7			
	350	34.8		1.5			
	360	818.0	29.2	35.3	1.3		
	420	131.6	27.1	5.7	1.2		
	1500	10.4	8.4	0.4	0.4		
TOTALS		2314.6	64.7			10.0	0.3
4	100	4.3		0.5			
	230	16.2		1.8			
	300	15.8		1.8			
	310	69.5		7.8			
	500	411.2	146.9	45.9	16.4		
	670	219.1	118.8	24.5	13.3		
	1100	158.8	116.8	17.7	13.1		
TOTALS		894.9	382.5			3.9	1.7

(continued)

TABLE 39. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5	110	64.4		0.7			
	120	79.1		0.9			
	180	20.8		0.2			
	200	14.4		0.2			
	270	3.8		0.1			
	280	554.2		6.3			
	310	3.5		0.1			
	320	1338.3		15.3			
	350	87.6		1.0			
	450	177.2	47.9	2.0	0.5		
	470	5773.1	1776.3	66.1	20.3		
	500	447.2	159.7	5.1	1.8		
	800	170.4	106.5	2.0	1.2		
TOTAL		8734.1	2090.5			37.7	9.0
6	100	55.1		0.8			
	110	20.8		0.3			
	130	6.4		0.1			
	150	.6		0.1			
	300	1358.6		18.5			
	310	1299.4		17.7			
	330	446.1		6.1			
	400	2057.0	321.4	28.0	4.4		
	540	66.8	27.6	0.9	0.4		
	580	1054.2	484.9	14.3	6.6		
	600	157.3	75.6	2.1	1.0		
	800	34.2	21.4	0.5	0.3		
	860	745.7	487.6	10.1	6.6		
	900	55.5	37.3	0.8	0.5		
TOTALS		7358.1	1455.8			31.8	6.3
10	160	1.2		0.3			
	190	1.6		0.3			
	200	44.6		9.7			
	250	87.4		19.0			
	300	206.7		44.8			
	400	118.8	18.6	25.8	4.0		
TOTALS		460.3	18.6			2.0	0.1

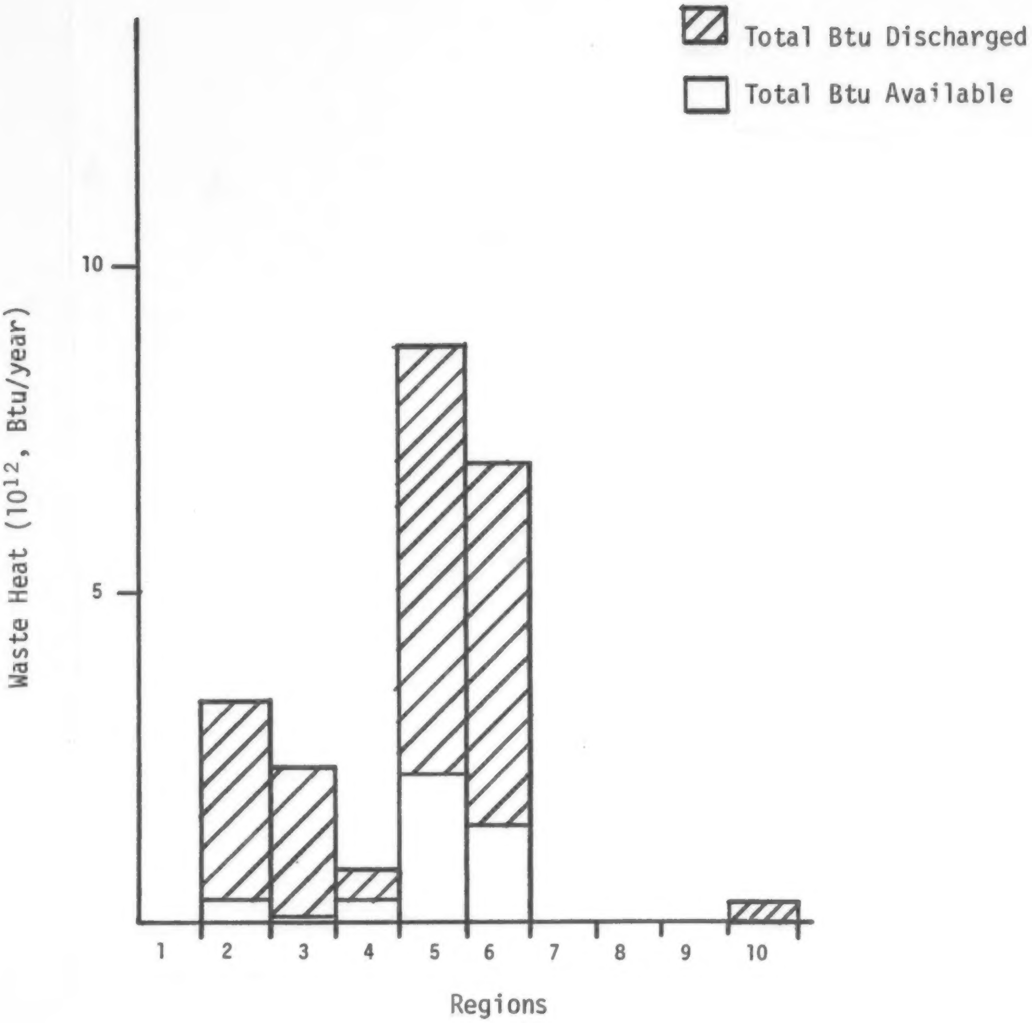

Figure 33. Regional totals for Alkalies and Chlorine (SIC 2812), (1977).

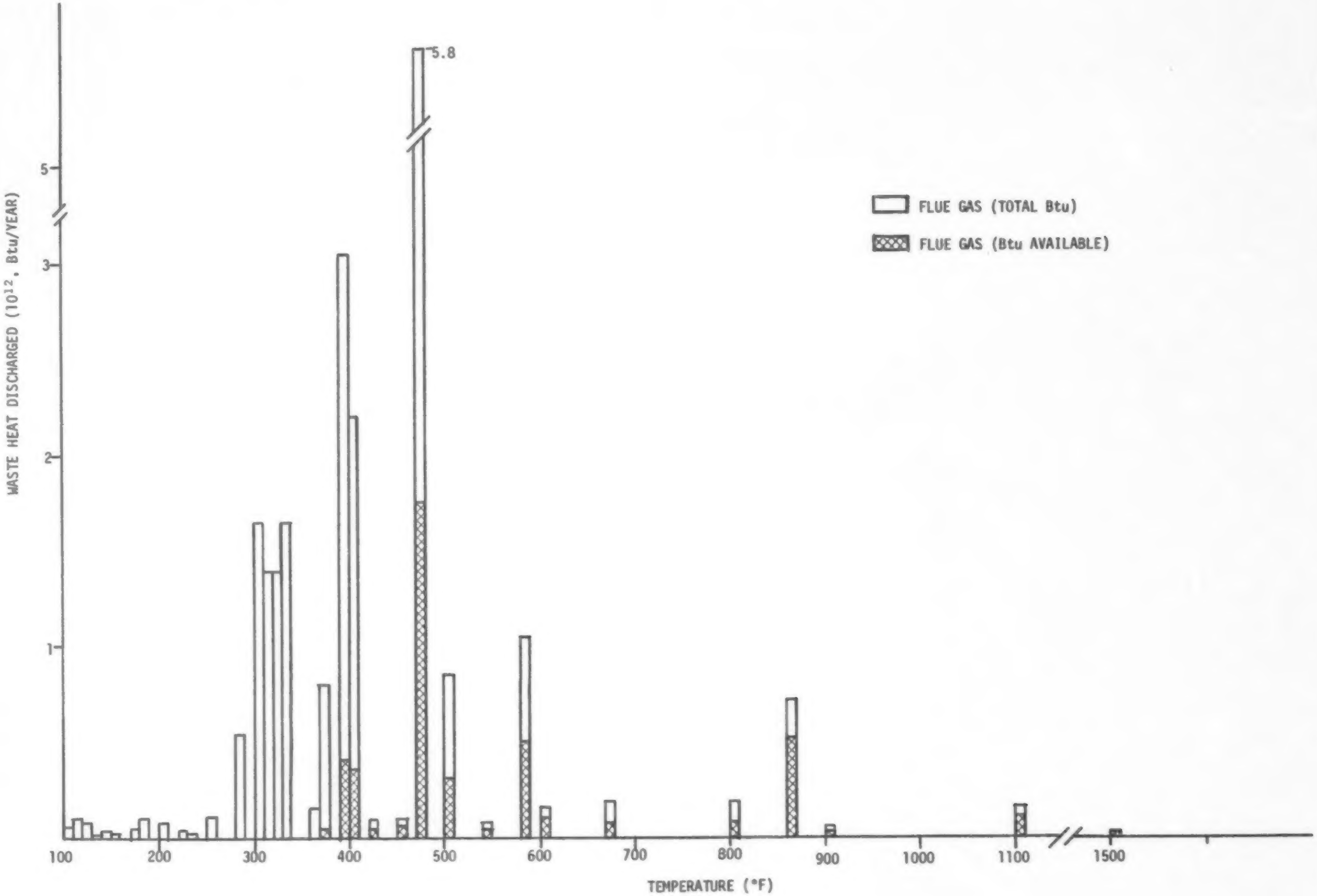

Figure 34. Waste heat temperature profile for Alkalies and Chlorine (SIC 2812).

INDUSTRIAL GASES (SIC 2813)

Introduction

Those establishments primarily engaged in manufacturing gases for sale in compressed, liquid, or solid form are included in the Standard Industrial Classification 2813. Gases which are produced as intermediates are included in the same classification as the major products. Consequently, the gases included in the classification are the compound gases; acetylene (C_2H_2), carbon dioxide (CO_2), and the elemental gases; argon (A), helium (He), hydrogen (H_2), nitrogen (N_2), and oxygen (O_2). Note should be made that processes for the captive production of these gases, such as the production and consumption of hydrogen for synthetic ammonia, are not included in this classification.

Within SIC 2813, the manufacturing process consuming the greatest portion of the energy is the distillation of air for the subsequent production of oxygen and nitrogen. Therefore, this report will focus on this process and its contribution of waste heat to this SIC classification.

High purity oxygen (99.5%) and nitrogen are produced commercially by a process of liquefaction and subsequent rectification of air. By using this process, or various modifications of this process, it is possible to produce liquid or gaseous oxygen ranging in purity from about 90% to 99.5%.

Geographical Distribution

Due to the expense involved in the storage and transportation of these higher volume industrial gases, air liquefaction plants tend to be located in close proximity to their major points of consumption. Consequently, the location of these plants is fairly evenly distributed throughout the United States.

Energy Consumption

The production of oxygen and nitrogen makes almost exclusive use of electrical energy, the majority of which is used for the compression of air. The amount of compression necessary is, however, dependent upon both the design of the liquefaction-rectification columns and the extent of heat exchange utilized between the feed and product. Approximately 264 Kwh/ton of O_2 (900,770 Btu/ton of O_2) are reportedly consumed in the compression of air. In order to account for other miscellaneous electrical consumptions, as required for product storage, handling, and pollution control devices, the total United States production of oxygen was compared to the total electrical consumption by these facilities and it was estimated that about 293 Kwh/ton of O_2produced (999,716 Btu/ton of O_2) are consumed.

Point Source of Waste Heat

The only major source of waste heat discharged to the environment by air liquefaction plants results from the heat rejected from the compressors. The heat content of this hot air stream (250°F) was estimated at 571,500

Btu/ton of oxygen produced. Depending upon the economics of plant size and the availability of water for a heat sink, this heat may be discharged directly to the atmosphere or may exit through a variety of wet cooling processes. If conventional industrial cooling practices are assumed, with a differential temperature of 30°F, approximately 2,200 gallons of cooling water would be discharged per ton of oxygen produced. This waste heat stream represents about 57% of the electric energy required to produce one ton of oxygen.

Discussion - Tables and Graphs

The total flue gas waste heat discharged by Industrial Gases (SIC 2813) is presented in Table 40. This table indicates that more than 25% of this industry's purchased fuels and electricity is discharged as waste heat. One third of this discharged waste heat was discharged at temperatures greater than 350°F.

Table 41 lists the waste heat discharged according to their discharge temperature and EPA region. Only two EPA regions, 3 and 6, are significant dischargers of waste heat in this industry. These two regions together account for 93% of the total flue gas waste heat. No discharges were reported for EPA regions 1, 7, 8, 9, and 10. This data is further summarized in Figure 35.

A waste heat temperature profile for this industry is presented in Figure 36. The most significant discharge temperatures were 700°F and 470°F. Together, these two temperature discharges account for almost 45% of the total waste heat discharged by this industry.

TABLE 40. TOTAL WASTE HEAT DISCHARGED BY INDUSTRIAL GASES (SIC 2813)

② IPP #	DESCRIPTION	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	% Btu Available	%WASTE ① Heat
-	Flue Gases					
BL	Process, NEC	100-1300	1681.73	726.90	43.22	1.40
1	Process, NEC	120-400	148.62	0.90	0.61	0.12
3	Process, NEC	480-700	582.14	278.59	47.86	0.48
4	Process, NEC	190-200	387.26	0.00	0.00	0.32
10	Combustion, Coal	340	1805.16	0.00	0.00	1.50
60	Combustion, Coal	470	6563.20	2019.45	30.77	5.47
00	Combustion, NEC	300-1000	19678.21	7710.64	39.18	16.41
	Total Flue Gases	100-1300	30846.32	10736.48	34.81	25.70

① Based on purchased fuels & electricity

② NEDS data, EPA 450/2-76-005 OAQPS guidelines

TABLE 41. REGIONAL WASTE HEAT DISCHARGED BY INDUSTRIAL GASES (SIC 2813)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	0.04		0.3			
	110	3.49		28.5			
	150	2.05		16.7			
	160	0.02		0.2			
	190	2.59		21.1			
	200	0.01		0.1			
	290	0.14		1.1			
	320	0.32		2.6			
	350	3.58		29.2			
TOTAL		12.25	0.0			0.1	0.0
3	140	6.9		0.1			
	320	1674.6		10.6			
	340	1805.9		11.5			
	350	95.9		0.6			
	390	11.9	1.5	0.1	0.1		
	400	2277.5	355.9	14.4	2.3		
	460	844.2	244.4	5.4	1.6		
	470	6563.2	2019.4	41.6	12.8		
	500	366.3	130.8	2.3	0.8		
	600	1540.2	740.5	9.8	4.7		
	900	221.1	148.3	1.4	0.9		
	1000	355.8	251.4	2.3	1.6		
TOTALS		15763.5	3892.2			51.1	12.6
4	190	371.1		17.7			
	200	15.6		0.7			
	340	390.6		18.6			
	480	457.8	148.8	21.8	7.1		
	550	131.9	56.1	6.3	2.7		
	700	373.2	210.7	17.8	10.0		
	750	18.3	10.9	0.9	0.5		
	1100	161.6	118.8	7.7	5.7		
	1300	179.4	139.7	8.5	6.6		
TOTALS		2100.1	685.0			6.8	2.2

(continued)

TABLE 41. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5	370	0.9	0.1	7.8	0.9		
	400	10.6	1.7	92.2	14.8		
TOTAL		11.5	1.7			0.1	0.1
6	120	142.9		1.1			
	200	2.8		0.1			
	300	831.0		6.4			
	440	30.2	7.5	0.2	0.1		
	450	2396.4	647.7	18.2	5.0		
	600	305.2	146.7	2.4	1.1		
	650	452.2	238.0	3.5	1.8		
	700	6813.0	3846.1	52.6	29.7		
	750	285.7	170.6	2.2	1.3		
	800	129.0	80.6	1.0	0.6		
	840	7.1	4.6	0.1	0.1		
	850	1564.3	1015.8	12.1	7.8		
		12959.7	6157.5			42.0	20.0

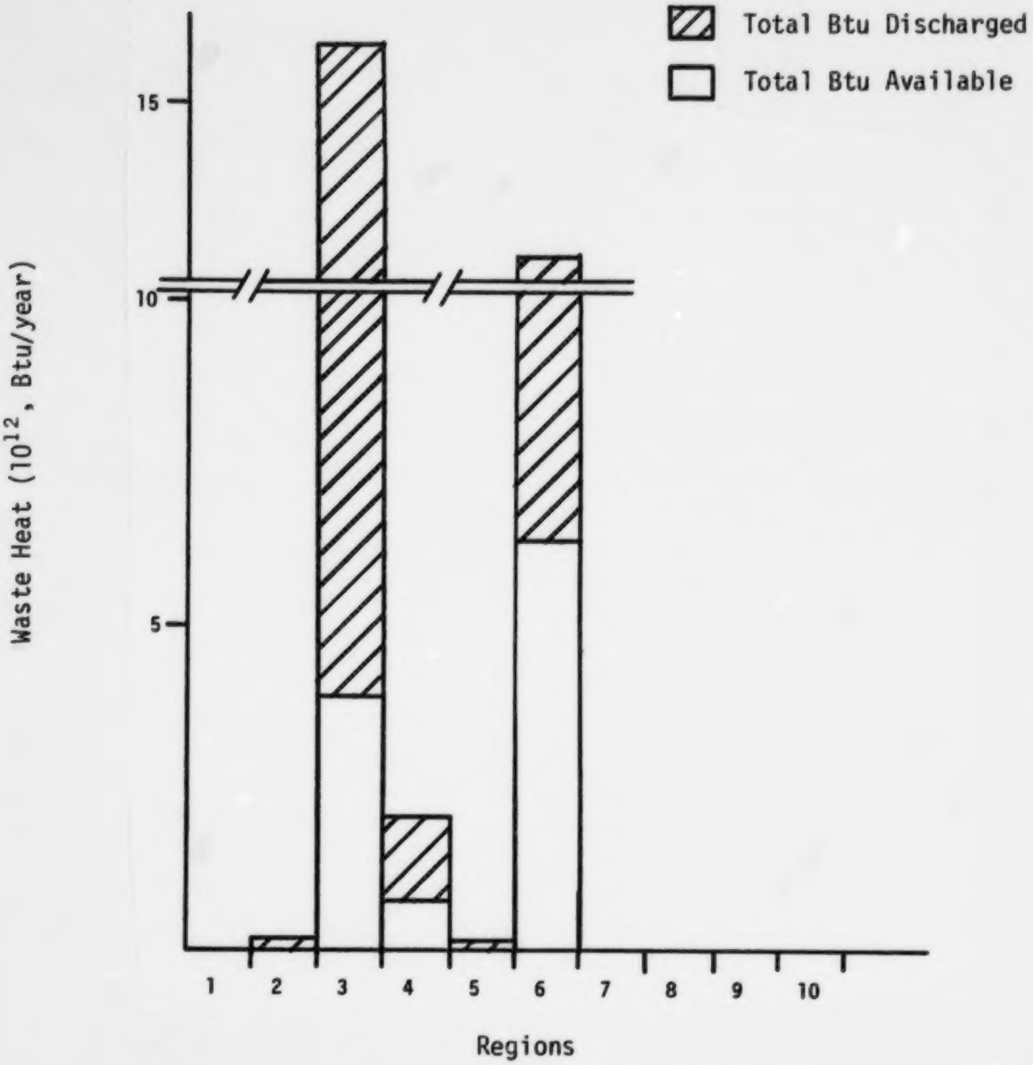

Figure 35. Regional totals for Industrial Gases (SIC 2813), (1977).

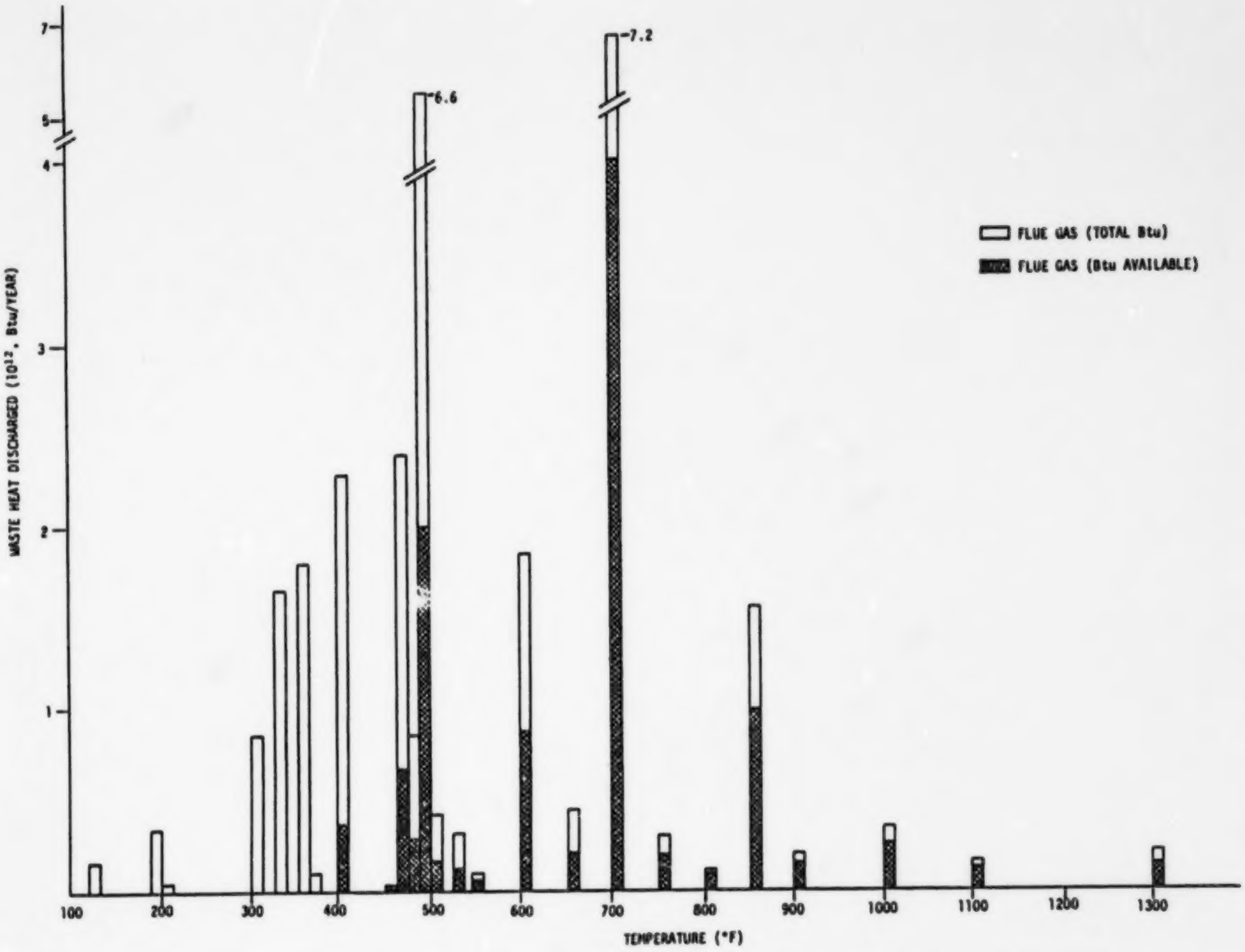

Figure 36. Waste heat temperature profile for Industrial Gases (SIC 2813).

INDUSTRIAL INORGANIC CHEMICALS (SIC 2819)

Introduction

This industry is defined as all industries producing inorganic chemicals which are not elsewhere classified. Since this industry is widely diversified with respect to both product mixes and processes utilized, it was determined that a discussion of any individual process or product would not be representative.

Point Sources of Waste Heat

Due to the extent of process diversification within this industrial classification, it was not possible to identify wastewater and cooling waters which could be considered representative of the industry. Therefore, only waste heat discharged as flue gases are presented according to the process identifications established by the National Emission Data System of the OAQPS, EPA.

Discussion - Tables and Graphs

The total flue gas waste heat discharged by SIC 2819 is presented in Table 42. This indicates that flue gases alone account for 47% of the industry's purchased fuels and electricity. Almost half (42%) of this energy is contained in flue gases at temperatures greater than 350°F.

Table 43 presents a breakdown of the flue gas waste heat according to discharge temperature and EPA region. The most significant discharge region is EPA region 5 which alone accounted for 52% of the total flue gas discharged and 31% of the total flue gas discharged at temperatures greater than than 350°F. Note should be made of the fact that 85% of EPA region 5's waste heat is charged at 850°F. This data is further summarized in Figure 37.

A waste heat temperature profile for this industry is presented in Figure 38. This figure clearly shows that the most significant waste heat discharge temperature was 850°F. This discharge temperature alone accounts for 44% of the total flue gas waste heat discharged by SIC 2819.

TABLE 42. TOTAL WASTE HEAT DISCHARGED BY INDUSTRIAL INORGANIC CHEMICALS, NEC (SIC 2819)

IPP② #	DESCRIPTION	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	% Btu Available	%Waste① Heat
	Flue Gases					
BL	Process, NEC	100-3000	45703.85	14326.39	31.35	9.59
1	Thermal Process	100-1300	105493.56	67433.96	63.92	22.15
2	Contact Process	100-700	5434.15	51.07	0.94	1.14
3	Lead Chamber Process	120-870	14857.54	2374.52	15.98	3.12
4	Recovery Incinerator	100-550	3886.32	223.32	5.75	0.82
5	Claus	120-700	812.57	278.10	34.23	0.17
6	Coke Dryer	220	18.52	0.00	0.00	0.00
8	Stack	250	120.48	0.00	0.00	0.03
9	Calcination	150	0.30	0.00	0.00	0.00
10	Combustion Coal	210-1750	413.89	192.75	46.57	0.09
11	Process, NEC	100-370	834.46	18.14	2.17	0.18
12	Process, NEC	100-170	294.64	0.00	0.00	0.06
26	Process, NEC	120	0.52	0.00	0.00	0.00
30	Combustion, Coal	350-600	6243.87	1093.21	17.51	1.31
70	Combustion, Coal	600-620	1662.20	819.86	49.32	0.35
99	Combustion, NEC	100-1000	365.61	49.98	13.67	0.08
00	Combustion, NEC	110-1800	40447.02	9136.77	22.59	8.50
	Totals	100-3000	226589.52	95998.07	42.36	47.59

① Based on purchased fuels & electricity

② NEDS data, EPA 450/2-76-005 OAQPS guidelines

TABLE 43. REGIONAL WASTE HEAT DISCHARGED BY INDUSTRIAL INORGANIC CHEMICALS, NEC (SIC 2819)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	110	7.8		2.0			
	140	2.6		0.7			
	200	11.2		2.8			
	330	136.0		34.5			
	470	76.4	23.5	19.4	6.0		
	530	5.5	2.2	1.4	0.6		
	600	52.4	25.2	13.3	6.4		
	900	102.3	68.6	26.0	17.4		
TOTALS		394.2	119.5			0.2	0.1
2	100	30.9		0.3			
	110	9.8		0.1			
	120	12.7		0.1			
	130	24.3		0.3			
	140	18.1		0.2			
	150	18.1		0.2			
	160	11.6		0.1			
	170	223.5		2.4			
	180	51.4		0.6			
	190	117.3		1.3			
	300	198.9		2.2			
	320	2199.9		24.0			
	330	582.8		6.4			
	350	742.6		8.1			
	400	9.6	1.5	0.1	0.1		
	450	202.5	54.7	2.2	0.6		
	500	950.3	339.4	10.4	3.7		
	530	0.2	0.1	<0.1	<0.1		
	550	480.8	204.6	5.2	2.2		
	600	877.7	422.0	9.6	4.6		
	650	142.6	75.0	1.6	0.8		
	700	2025.5	1143.4	22.1	12.5		
	790	0.6	0.4	<0.1	<0.1		
	1000	125.7	88.8	1.4	1.0		
	1200	11.0	8.4	0.1	0.1		
	1400	5.8	4.7	0.1	0.1		
	1500	100.0	81.0	1.1	0.9		
TOTALS		9174.4	2423.9			4.1	1.1
3	100	0.9		<0.1			
	110	3.1		<0.1			
	120	4.7		<0.1			
	140	35.4		0.2			
	150	9.9		0.1			

(continued)

TABLE 43. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
3 (Cont)	160	8.5		0.1			
	170	1938.5		13.6			
	180	341.2		2.4			
	300	174.3		1.2			
	350	787.9		5.5			
	390	5250.6	677.5	36.9	4.8		
	400	68.8	10.8	0.5	0.1		
	430	654.8	149.7	4.6	1.1		
	460	2739.7	793.1	19.3	5.6		
	470	296.4	91.2	2.1	0.6		
	480	1480.4	481.1	10.4	3.4		
	500	377.3	134.8	2.7	0.9		
	600	36.0	17.3	0.3	0.1		
	1100	23.0	16.9	0.2	0.1		
TOTALS		14231.8	2372.4			6.4	1.1
4	100	236.1		0.9			
	110	96.6		0.4			
	120	972.7		3.8			
	130	216.3		0.8			
	140	212.5		0.8			
	150	336.0		1.3			
	160	931.8		3.6			
	170	321.4		1.3			
	180	508.2		2.0			
	190	690.9		2.7			
	200	394.2		1.5			
	210	7.8		<0.1			
	220	222.1		0.9			
	240	1.7		<0.1			
	250	9.8		<0.1			
	260	165.9		0.6			
	280	65.8		0.3			
	300	322.0		1.3			
	310	37.8		0.1			
	320	65.3		0.3			
	330	509.4		2.0			
	340	343.7		1.3			
	350	1351.2		5.3			
	360	168.0	6.0	0.7	0.1		
	380	110.3	11.0	0.4	0.1		
	400	661.6	103.4	2.6	0.4		
	410	100.1	18.2	0.4	0.1		
	450	1451.8	392.4	5.7	1.5		

TABLE 43. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4 (Cont)	460	160.8	46.5	0.6	0.2		
	470	419.1	129.0	1.6	0.5		
	500	7698.2	2749.4	30.1	10.8		
	530	545.7	218.3	2.1	0.9		
	550	1358.5	578.1	5.3	2.3		
	570	1044.3	468.9	4.1	1.8		
	580	40.6	18.7	0.2	0.1		
	600	852.0	409.6	3.3	1.6		
	610	4.7	2.3	<0.1	<0.1		
	620	16.2	8.1	0.1	0.1		
	700	57.4	32.4	0.2	0.1		
	720	205.2	118.6	0.8	0.5		
	750	9.2	5.5	<0.1	<0.1		
	800	101.1	63.2	0.4	0.2		
	870	1498.3	986.2	5.9	3.9		
	1000	322.7	228.0	1.3	0.9		
	1100	105.4	77.5	0.4	0.3		
	1200	60.5	45.9	0.2	0.2		
	1500	0.3	0.3	0.1	0.1		
	1600	250.5	206.0	1.0	0.8		
	1800	287.4	242.3	1.1	0.9		
TOTALS		25549.2	7165.7			11.5	3.2
5	100	0.1		<0.1			
	110	8.8		<0.1			
	120	188.7		0.2			
	140	62.1		0.1			
	150	54.8		<0.1			
	160	329.1		0.3			
	170	140.3		0.1			
	180	218.6		0.2			
	190	33.7		<0.1			
	200	133.5		0.1			
	210	5.8		<0.1			
	300	12.3		<0.1			
	340	110.7		0.1			
	350	1996.1		1.7			
	360	3019.1	107.8	2.6	0.1		
	380	704.9	70.5	0.6	0.1		
	400	2976.2	465.0	2.5	0.4		
	410	916.2	166.6	0.8	0.1		
	450	228.7	61.8	0.2	0.1		
	470	78.6	24.2	0.1	0.1		
	600	2711.4	1303.6	2.3	1.1		
	620	1077.5	538.7	0.9	0.5		

TABLE 43. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
5 (Cont)	650	138.6	73.0	0.1	0.1		
	850	100714.5	65399.0	85.7	55.7		
	1400	460.1	366.0	0.4	0.3		
	1580	1169.6	959.1	1.0	0.8		
TOTALS		117490.1	69535.3			52.8	31.2
6	100	2820.6		6.5			
	110	599.5		1.4			
	120	312.6		0.7			
	130	286.9		0.7			
	140	261.4		0.6			
	150	1125.5		2.6			
	160	392.8		0.9			
	170	691.2		2.4			
	180	1053.5		2.4			
	190	630.4		1.5			
	200	527.9		1.2			
	210	123.9		0.3			
	220	13.2		0.1			
	240	0.2		0.1			
	250	4.4		0.1			
	260	469.3		1.1			
	270	38.1		0.1			
	280	390.1		0.9			
	300	5166.5		12.0			
	310	52.9		0.1			
	320	521.9		1.2			
	340	89.0		0.2			
	350	131.9		0.3			
	370	2177.8	150.2	5.0	0.3		
	390	2152.6	277.8	5.0	0.6		
	400	110.5	17.3	0.3	0.1		
	420	956.8	197.0	2.2	0.5		
	430	1071.9	245.0	2.5	0.6		
	440	2.0	0.5	0.1	0.1		
	480	4408.8	1432.8	10.2	3.3		
	490	3185.8	1087.9	7.4	2.5		
	500	1951.1	696.8	4.5	1.6		
	520	21.2	8.2	0.1	0.1		
	530	328.1	131.3	0.8	0.3		
	550	1.5	0.6	0.1	0.1		
	560	172.0	75.2	0.4	0.1		
	570	138.1	62.0	0.3	0.1		
	640	208.6	108.0	0.5	0.3		

TABLE 43. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PRECENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6 (Cont.)	650	58.5	30.8	0.1	0.1		
	680	8.7	4.8	0.1	0.1		
	700	245.8	138.8	0.6	0.3		
	720	45.2	26.1	0.1	0.1		
	730	784.6	458.7	1.8	1.1		
	750	170.7	101.9	0.4	0.3		
	800	189.8	118.6	0.4	0.3		
	850	127.0	82.4	0.3	0.2		
	880	288.4	191.1	0.7	0.4		
	900	1377.4	923.8	3.2	2.1		
	970	276.5	192.6	0.6	0.4		
	1000	2368.8	1864.3	6.1	4.3		
	1090	83.9	61.5	0.2	0.1		
	1100	282.9	208.0	0.7	0.5		
	1120	382.7	283.3	0.9	0.7		
	1140	389.4	290.2	0.9	0.7		
	1170	1751.1	1317.4	4.1	3.1		
	1190	444.1	336.1	1.0	0.8		
	1200	584.3	443.5	1.4	1.0		
	1300	51.4	40.1	0.1	0.1		
	1350	428.7	337.6	1.0	0.8		
	2840	58.6	52.9	0.1	0.1		
TOTALS		43147.8	11995.1			19.4	5.4
7	100	44.1		0.7			
	110	54.4		0.9			
	120	78.3		1.3			
	130	27.0		0.4			
	140	285.2		4.6			
	150	129.1		2.1			
	170	60.7		1.0			
	180	150.9		2.4			
	190	35.4		0.6			
	200	20.4		0.3			
	210	271.4		4.4			
	220	18.5		0.3			
	230	5.6		0.1			
	240	98.2		1.6			
	250	120.5		2.0			
	270	511.3		8.3			
	300	209.5		3.4			
	340	31.9		0.5			
	350	1989.9		32.2			
	370	263.1	18.1	4.3	0.3		
	420	262.4	54.0	4.3	0.9		

TABLE 43. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
7 (Cont)	470	203.9	62.7	3.3	1.0		
	500	105.2	37.6	1.7	0.6		
	510	363.6	135.3	5.9	2.2		
	520	12.3	4.8	0.2	0.1		
	550	524.8	223.3	8.5	3.6		
	600	3.5	1.7	0.1	0.1		
	750	51.7	30.9	0.8	0.5		
	1420	12.1	9.7	0.2	0.2		
	1750	229.9	192.7	3.7	3.1		
TOTALS		6175.0	770.8			2.8	0.3
8	100	40.4		8.4			
	110	50.0		10.4			
	160	29.2		6.1			
	200	1.1		0.2			
	430	42.4	9.7	8.8	2.0		
	450	22.6	6.1	4.7	1.3		
	650	293.7	154.6	61.3	32.2		
TOTALS		479.4	170.4			0.2	0.1
9	130	43.8		21.1			
	160	84.1		40.4			
	220	80.1		38.5			
TOTALS		208.0	0.0			0.1	0.0
10	100	36.4		0.6			
	110	228.1		3.9			
	130	720.7		12.4			
	140	350.8		6.0			
	150	19.2		0.3			
	170	132.6		2.3			
	300	229.3		3.9			
	350	667.4		11.5			
	380	23.6	2.4	0.4	0.1		
	400	1069.4	167.1	18.4	2.9		
	450	463.3	125.2	8.0	2.2		
	600	1618.3	778.0	27.8	13.4		
	3000	256.1	232.5	4.4	4.0		
TOTALS		5815.3	1305.1			2.6	0.6

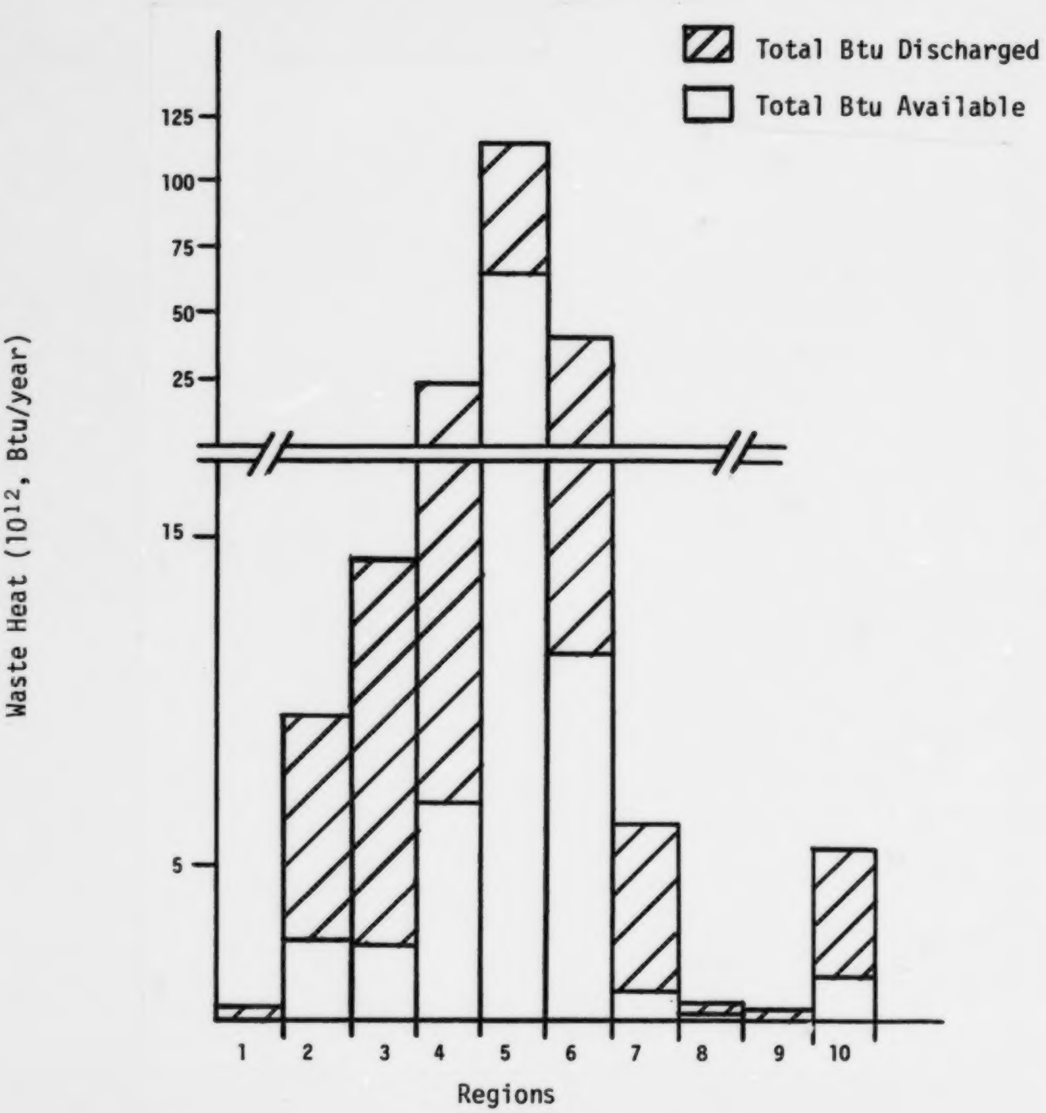

Figure 37. Regional totals for Industrial Inorganic Chemicals, NEC (SIC 2819), (1977).

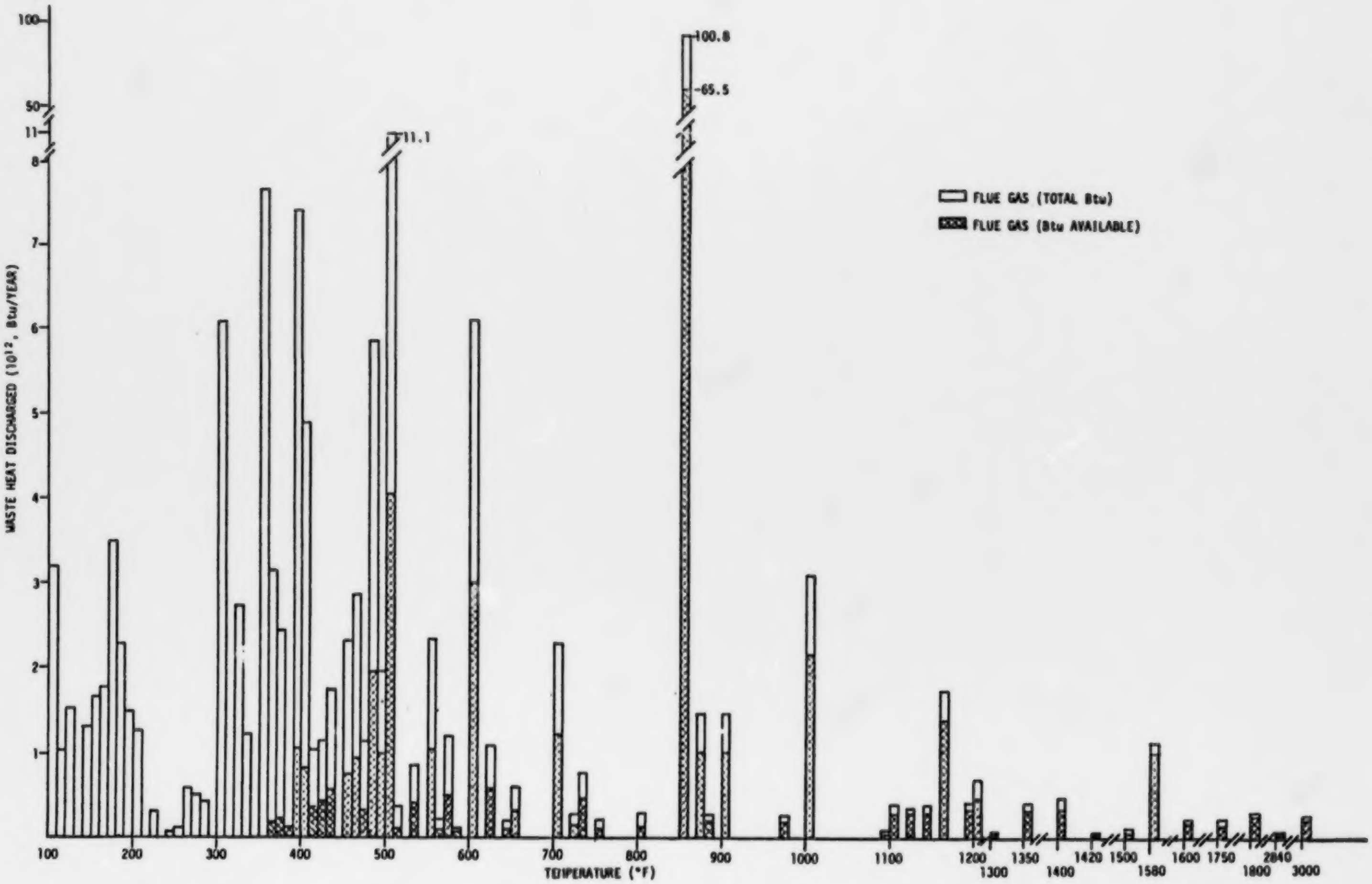

Figure 38. Waste heat temperature profile for Industrial Chemicals, NEC (SIC 2819).

CYCLIC CRUDES AND INTERMEDIATES (SIC 2865)

Introduction

This industry is defined as all industries primarily engaging in the manufacture of Cyclic Crudes and their Intermediates. This industry is very diversified with respect to processes used and product mix. Consequently, this discussion of specific process waste heat discharged will focus on the largest energy consuming process, Styrene.

Styrene

Styrene is produced by catalytically alkylating benzene with ethylene and then catalytically dehydrogenating the resulting ethylbenzene in the presence of steam or benzene. The alkylator feed consists of dry benzene, ethylene and granular aluminum chloride or boron trifluoride catalyst. Alkylation may also be carried out in the vapor phase at 572°F and 600 psig, with supported phosphoric acid or silica-alumina catalyst.

Geographic Distribution

Styrene production is primarily concentrated along the Gulf Coast of Texas and Louisiana. The United States production of styrene was expected to grow from 6% to 8% per year.

Energy Consumption

In the manufacture of ethylbenzene, distillation is the main energy consuming operation, accounting for about three-quarters of the total energy requirements.

In the manufacture of styrene from ethylbenzene, the major energy consuming steps are the heating of the reactants and steam and the distillation of the reactor exit stream. These operations account for more than nine-tenths of the required energy.

Point Sources of Waste Heat

In the production of the ethylbenzene feed for styrene production, the main waste heat streams are in the form of cooling water. Cooling and scrubbing of the gaseous reactor product stream produces about 890,000 Btu of waste heat per ton of styrene produced. Cooling and decanting of the liquid reaction products also occurs at about 210°F. For a ton of styrene product, 330,000 Btu were rejected and 1,350 gallons of cooling water were required.

The cooling water necessary for condensing the distillation column reflux is far more significant. Each ton of styrene production necessitates the removal of 3,560,000 Btu from the overheat streams utilizing about 14,400 gallons of cooling water. The largest amount of rejected heat in the production of styrene is from cooling water required for desuperheating and cooling the dehydrogenation reactor product stream. For this, approximately 1,960,000 Btu is rejected at 440°F and 17,400,000 Btu is rejected at 220°F.

The overheat streams from distillation were discharged at from 110°F to 150°F. Around 4,800,000 Btu per ton of styrene were rejected from these streams. Assuming a 30°F differential temperature, about 19,400 gallons of cooling water per ton of styrene would be required.

In styrene production from ethyl benzene, around 88,000 cubic feet of stack gas at 400°F was given off for each ton or product. This accounts for approximately 620,000 Btu of waste heat per ton of product. The annual Btu discharged by this stream is incorporated in Table 44 along with all other miscellaneous combustion and process offgases. The total rejected heat from cooling and process water streams amounts to 28.98 million Btu per ton of product.

Discussion - Tables and Graphs

Table 44 presents the total flue gas waste heat discharged by the cyclic crudes and intermediates industrial classification in 1977. This indicates that only 5.5% of this industry's purchased fuels and electricity were discharged as flue gas waste heat. Almost half of this energy was contained in waste heat flue gases at temperatures over 350°F.

These data is further differentiated by EPA region and discharge temperature in Table 45. This table indicates that waste heat discharges from this industry were only discharged in EPA regions 1, 3, 4, and 6. EPA region 6 alone accounting for 87% of the total flue gas waste heat discharged. This data is further summarized in Figure 39.

A waste heat temperature profile for this industrial classification is presented in Figure 40. This figure clearly shows that the majority of waste heat discharged by this industry were discharged at relatively high temperatures. Consequently, almost half of this waste heat energy exists in flue gases greater than 350°F.

TABLE 44. TOTAL WASTE HEAT DISCHARGED BY CYCLIC CRUDES AND INTERMEDIATES (SIC 2865)

② IPP #	DESCRIPTION	Temperature Range (°F)	Total Btu ($x\ 10^9$)	Total Btu Available ($x\ 10^9$)	% Btu Available	%Waste Heat ①
	Flue Gases					
BL	Process, NEC	100-2000	5296.34	4255.29	80.34	2.95
1	Process, NEC	100-210	10.17	0.00	0.00	0.00
20	Combustion, Coal	360	696.93	24.89	3.57	0.39
00	Combustion, NEC	150-800	3886.46	353.94	9.11	2.16
	Totals	100-2000	9889.90	4634.12	46.86	5.50

① Based on purchased fuels & electricity

② NEDS data, EPA 450/2-76-005 OAQPS guidelines

TABLE 45. REGIONAL WASTE HEAT DISCHARGED BY CYCLIC CRUDES AND INTERMEDIATES (FLUE GASES ONLY) (SIC 2865)

EPA REGION	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	350	28.9		26.0			
	550	82.4	35.1	74.0	31.5		
TOTALS		111.3	35.1			1.1	0.4
3	100	17.1		1.6			
	150	0.1		0.1			
	210	10.2		0.9			
	230	11.4		1.1			
	240	13.4		1.2			
	300	29.8		2.7			
	360	696.9	24.9	64.3	2.3		
	400	100.1	15.6	9.2	1.4		
	600	182.0	88.0	16.9	8.1		
	700	17.5	9.9	1.6	0.9		
	800	3.8	2.4	0.4	0.2		
TOTALS		1083.8	140.7			11.0	1.4
4	120	4.1		4.6			
	400	53.8	8.4	60.6	9.5		
	550	21.0	8.9	23.6	10.0		
	750	10.0	6.0	11.3	6.8		
TOTALS		88.8	23.3			0.9	0.2
6	100	8.7		0.1			
	120	7.6		0.1			
	130	<0.1		<0.1			
	140	3.6		<0.1			
	160	9.6		0.1			
	200	35.3		0.4			
	210	0.2		<0.1			
	280	469.2		5.5			
	320	522.5		6.1			
	350	1303.5		15.1			
	400	978.4	152.9	11.4	1.8		
	460	42.4	12.3	0.5	0.1		
	500	82.5	29.5	1.0	0.3		
	510	107.0	39.8	1.2	0.5		
	1000	271.7	192.0	3.2	2.2		
	1700	2096.4	1747.0	24.4	20.3		
	1800	1840.8	1551.8	21.4	18.0		
	2000	825.9	709.8	9.6	8.2		
TOTALS		8605.2	4435.0			87.0	44.8

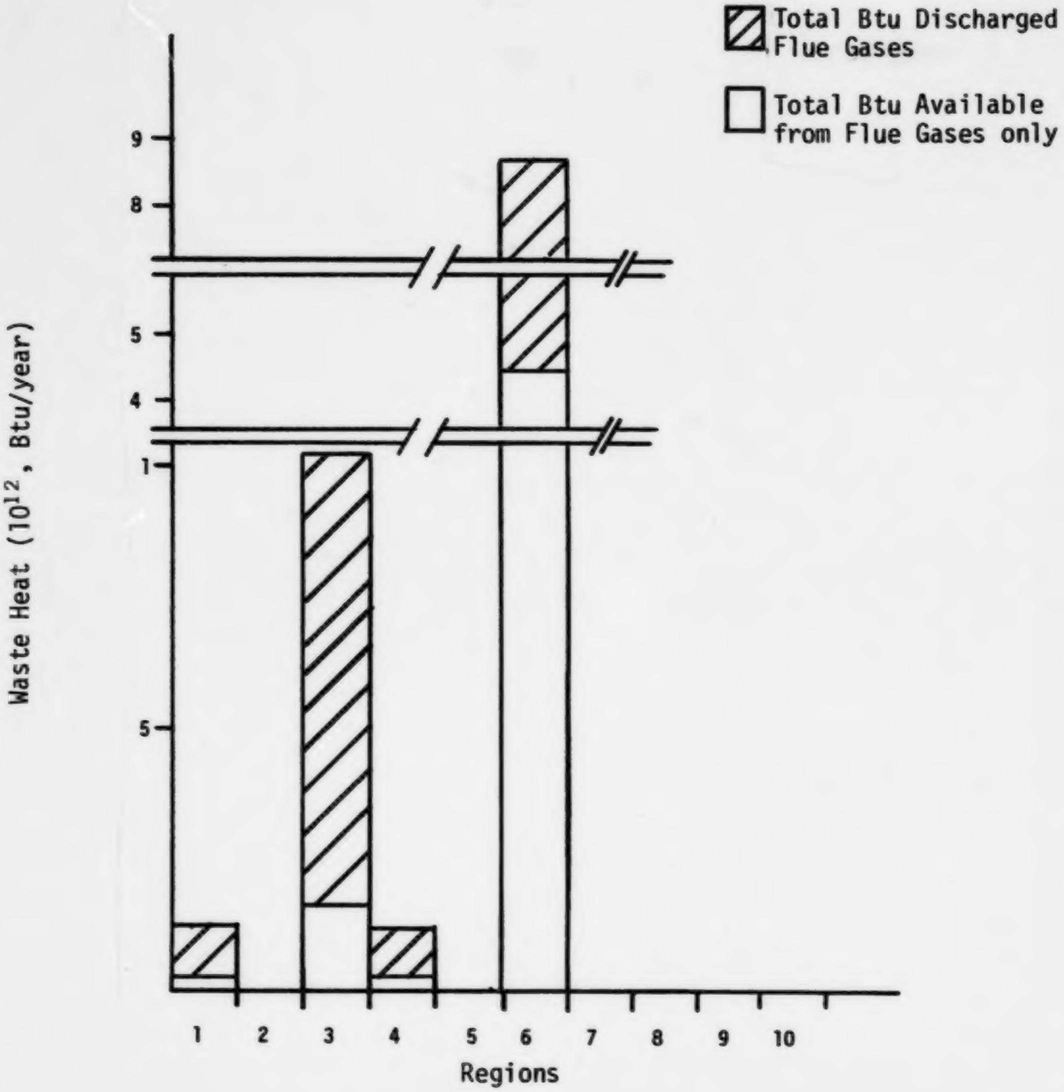

Figure 39. Regional totals for Cyclic Crudes and Intermediates (SIC 2865), (1977).

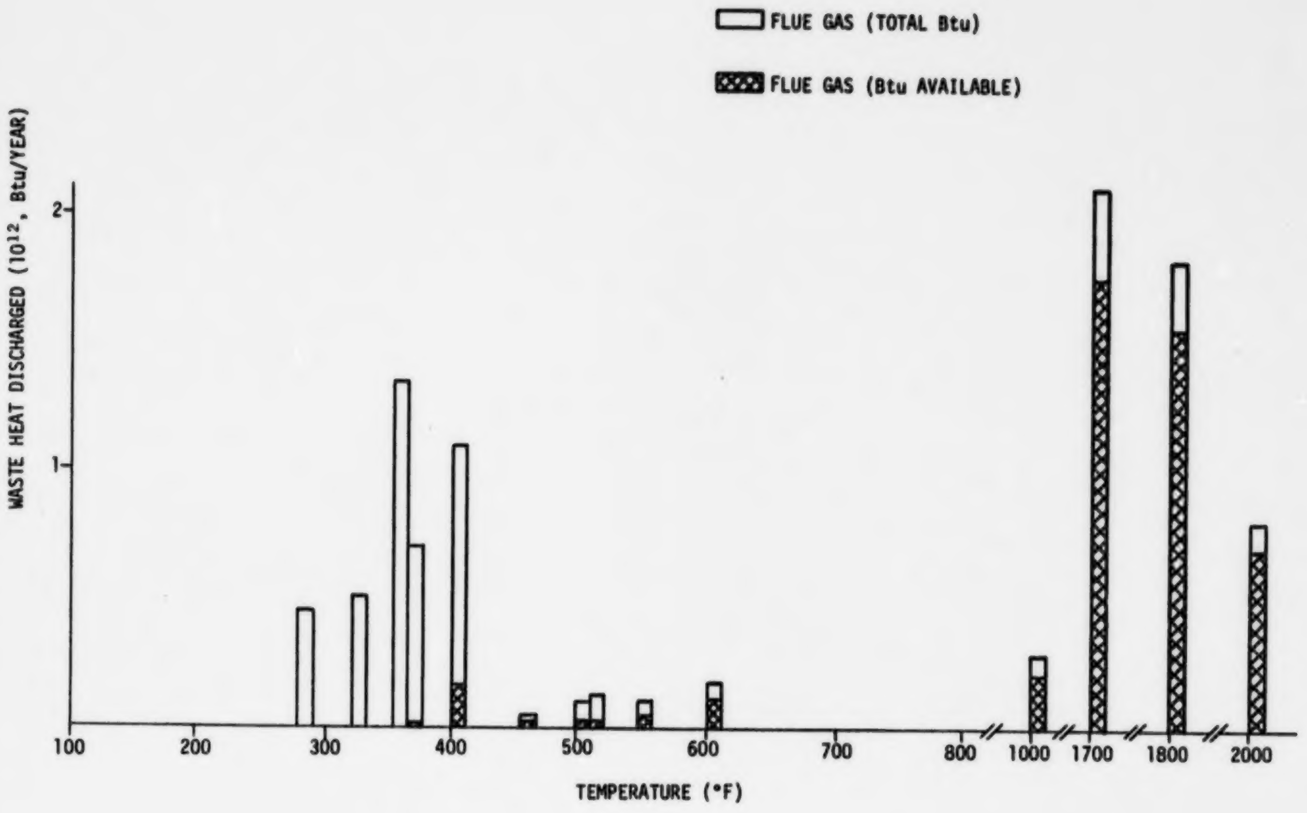

Figure 40. Waste heat temperature profile for Cyclic Crudes and Intermediates (SIC 2865).

INDUSTRIAL ORGANIC CHEMICALS (SIC 2869)

Introduction

This industry is defined as those establishments primarily engaged in the manufacture of organic chemicals not elsewhere classified. The major products produced within this industrial classification are: Olefins, Ethylene Oxide, Methyl Alcohol, and Formaldehyde.

Olefins

General

Olefins are defined as openchain hydrocarbons with one or more double bonds. Ethylene and propylene are the most important examples. Because of the current demand for ethylene, olefins plants are usually operated for maximum ethylene production, although propylene, carbon compounds, fuel oil pyrolysis gasoline, methane, and hydrogen are also produced.

Ethylene is the petrochemical feedstock used in greatest amount and its consumption was expected to increase at a rate of 7% annually through 1980. Because of economics of scale, olefins plants are very large. The most recent ethylene plants have annual capacities of around two billion pounds.

In the United States and Puerto Rico, in 1975, 70% of the production of ethylene and propylene resulted from the steam cracking of ethane, propane, and butane recovered from natural gas. The remainder of the production was based upon cracking of naphtha and gas oil. Cracking of the feed into olefins is done within a tubular furnace. The main process steps are steam cracking, quenching, compression, acid gas removal, water removal, demethanation, C_2 separation, C_3 separation, C_4 separation, and heavy fractionation.

Point Sources of Waste Heat

There are a number of significant waste heat streams from an olefins plant.

The main gaseous waste heat stream consists of approximately 233,000 cu. ft. of stack gas at 400°F accounting for 1,860,000 Btu/ton. This stream and all other gaseous discharges within SIC 2869 are incorporated in Table 46. The other significant waste heat streams were all water streams. The blowdown from refrigerant compressors was the largest waste heat stream in an olefins plant, closely followed by the blowdown from pyrolysis gas compression. These streams utilize 2,690 gallons of water with a differential temperature of 140°F, thus discharging 3,000,000 Btu of waste heat per ton of product.

Also associated with refrigeration are 3,500 gallons of water used to cool the compressed refrigerant. The cooling water has a differential temperature of 70°F, thus discharging 2×10^6Btu of waste heat per ton of product.

Blowdown associated with compression of the coolest pyrolysis gases consist of about 2,510 gallons per ton of ethylene. This effluent has a differential temperature of 140°F and provided 2.8 x 10^6Btu of waste heat.

Cooling of the pyrolysis gases and gas liquid separation are required between each compressor stage. Around 1,340 gallons of cooling water were required for each ton of ethylene. This stream has a differential temperature of 140°F and discharged 1.5 x 10^6Btu of waste heat per ton produced.

Quench water blowdown and cooling water for the quench water recycle stream have a differential temperature of 70°F and amount to 350 gallons per ton of ethylene. This results in the discharge of 200,000 Btu of waste heat.

The total rejected heat by process wastewaters and non-contact cooling waters from an olefins plant was 9.5 x 10^6Btu for every ton of ethylene produced. This was equivalent to an annual discharge of 28.5 x 10^{12}Btu.

Ethylene Oxide (SIC 2869)

General

Ethylene oxide is produce by oxidizing ethylene in the presence of a silver catalyst. In order to suppress the complete oxidation of ethylene to carbon dioxide, a trace quantity of anticatalyst may be added to the feed or effluent gases from the process.

The oxidation is carried out at atmospheric pressure and a temperature of from 520°F to 550°F. Around 60% of the ethylene oxide produced is used in making ethylene glycol. Surfactants consume 11%, glycol ethers use 7%, and 6.5% is used in making ethanolamines.

Energy Consumption

In the production of ethylene oxide, the part of the process consuming the greatest amount of energy is the oxidation step. Energy is also used in stripping and fractionation.

Geographical Distribution

Most ethylene oxide plants are located along the Gulf Coast of Texas and Louisiana. There are, however, some plants in Puerto Rico, Kentucky and Delaware.

Point Sources of Waste Heat

The only process stream generatated in ethylene oxide production is the blowdown from the stripping tower recycle stream. Since this stream may contian more than 2% ethylene glycol, it is usually sent to processing in an onsite ethylene glycol plant. More than 85% of the ethylene oxide produced is used on-site.

A number of potential rejected heat streams were identified, but no quantitative data was available. These streams were cooling waters for the reaction produces, and for the overheat streams from the stripping and fractionating columns. Flue and offgases were incorporated in Table 46.

Methyl Alcohol

General

Methanol is synthesized by reacting hydrogen with carbon monoxide at high pressures. In the United States, the reactants are usually obtained from reformed natural gas or naptha.

Natural gas is desulfurized, preheated, and mixed with carbon dioxide and steam. The mixture is passed through catalyst packed furnace tubes where the following reaction takes place at high temperatures:

$$3\ CH_4 + CO_2 + 2H_2O \rightarrow 4CO + 8H_2$$

Design reforming temperatures can be as high as 1600°F. The resulting synthesis gas is passed through waste heat boilers, heat exchangers, and water coolers before compression in multistage compressors to very high pressures.

About 1,015 million gallons of methyl alcohol were produced in the United States in 1977. About 43% was used in making formaldehyde and 10% was used as a general process solvent. It is also used as a feedstock in the production of a number of organic chemicals.

Energy Consumption

The fuel required to produce methanol from a natural gas feedstock is dependent upon the pressure at which methanation occurs. The entire fuel requirements may be met by purge gas from the synthesis loop. As much as 1.6×10^6Btu of fuel may be required to produce a ton of methanol.

In the case of greater fuel usage there is an accompanying decrease in feedstock requirements; conversely, with a lesser fuel requirement a greater amount of feed is necessary.

With a naptha feedstock the fuel requirement may range from 5 to 7 million Btu per ton of product, according to the synthesis pressure.

In methyl alcohol production, the process steps which consume the most energy are the reformer furnace, the converter, preheating, compression and distillation.

Geographical Distribution

With very few exceptions, methyl alcohol production in the United States is concentrated along the Gulf Coast of Texas and Louisiana.

Point Sources of Waste Heat

A number of possible waste heat discharges were identified for methyl alcohol production, but quantitative data on these streams was not available. Stack gas from the reformer furnace, which is incorporated in Table 46, is the only gaseous effluent. Possible aqueous rejected heat streams include water for cooling the synthesis gas, steam condensate blowdown from the turbines used to drive the compressors, and cooling water for condensing the methanol vapors from the converter. Where distillation is employed for product stream purification, there are two additional rejected heat streams. These are the cooling water used for condensing the overheat streams and the wastewater bottoms product.

Formaldehyde (SIC 2869)

General

Formaldehyde is produced from methanol, either by catalytic vapor-phase dehydrogenation, or oxidation. Formaldehyde and unreacted methanol in the reactor effluent are absorbed in water and then separated by distillation.

The main uses for formaldehyde in the United States are for ureaformaldehyde resins, about 30% of total production; phenolformaldehyde resins, 24%; and acetal resins, 9%. Formaldehyde is also used in the production of a number of other chemicals.

Energy Consumption

The most energy intensive process step in the production of formaldehyde is the reaction in which either oxidation of hydrogen or partial oxidation of methyl alcohol occurs, dependent upon the catalyst used. The energy consuming steps are preheating, which requires steam, and (in the case of a silver catalyzed process) fractional distillation of the absorbed reaction products.

Geographical Distribution

There is no heavy geographical concentration of formaldehyde production in the United States. However, most plants are located in coastal states.

Point Sources of Waste Heat

The major effluent heat streams in formaldehyde production are all water streams; steam condensate from preheating and vaporization, cooling water from absorption, water for product cooling, and, in the case of silver catalyzed processes, water for the condensation of overheat streams from distillation.

Discussion - Tables and Graphs

The total flue gas waste heat discharged by Industrial Organic Chemicals (SIC 2869) is presented in Table 46. This table indicates that this industry is rather efficient with respect to waste heat. This industry discharged only 10% of its purchased fuels and electricity as waste heat. The actual percent of waste heat discharged may be considerably lower since many processes within this SIC obtain energy from their feedstocks which are not considered purchased fuel and electricity.

A breakdown of the waste heat discharged is presented in Table 47. This table presents the quantities of waste heat discharged by EPA regions and identified the discharge temperatures. EPA region 6 alone accounts for 88% of the total waste heat discharged by this SIC. This data is further summarized in Figure 41.

Figure 42 presents the flue gas waste heat temperature profile for this industry. This figure indicates that the majority of waste heat discharged is at temperatures above 500°F and that almost half of the available waste heat is discharged at temperatures between 1400°F and 1800°F.

TABLE 46. TOTAL WASTE HEAT DISCHARGED BY INDUSTRIAL ORGANIC CHEMICALS, NEC (FLUE GASES ONLY) (SIC 2869)

② IPP #	DESCRIPTION	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	%Btu Available	%Waste Heat ①
	Flue Gases					
BL	Process, NEC	100-2600	42494.24	24074.31	56.55	4.22
1	Process, NEC	100-1200	2121.07	1004.53	47.36	0.21
20	Combustion, Coal	290	629.84	0.00	0.00	0.06
60	Combustion, Coal	250-720	480.43	211.90	44.11	0.05
70	Combustion, Coal	530	362.81	145.12	40.00	0.04
99	Combustion, NEC	100-600	228.26	102.54	44.92	0.02
00	Combustion, NEC	100-1400	63519.39	12886.89	20.29	6.31
	Total Flue Gases	100-2600	109836.04	38425.29	34.98	10.99

①Based on purchased fuels & electricity

②NEDS data, EPA/2-76-005 OAQPS guidelines

TABLE 47. REGIONAL WASTE HEAT DISCHARGED BY INDUSTRIAL ORGANIC CHEMICALS, NEC (FLUE GASES ONLY) (SIC 2869)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
2	100	0.4		<0.1			
	120	2.8		0.1			
	140	7.7		0.3			
	150	5.1		0.2			
	210	4.0		0.2			
	250	0.1		<0.1			
	270	455.7		20.5			
	300	379.2		17.0			
	390	0.1	<0.1	<0.1	<0.1		
	450	0.8	0.2	<0.1	<0.1		
	500	912.8	326.0	41.0	14.6		
	600	212.8	102.3	9.6	4.6		
	700	3.0	1.7	0.1	0.1		
	800	141.0	88.1	6.3	4.0		
	840	99.1	63.9	4.4	2.9		
	930	2.2	1.5	0.1	0.1		
	1000	0.1	0.1	0.1	0.1		
TOTALS		2227.0	583.8			2.0	0.5
3	100	0.2		<0.1			
	140	11.6		0.5			
	150	0.2		<0.1			
	160	0.6		<0.1			
	210	9.3		0.4			
	230	10.7		0.5			
	250	63.6		2.7			
	320	51.8		2.2			
	350	40.4		1.7			
	370	2.9	0.2	<0.1	0.1		
	450	106.5	28.8	4.5	1.2		
	470	78.7	24.2	3.3	1.0		
	500	110.6	39.5	4.7	1.7		
	560	243.9	106.7	10.3	4.5		
	600	46.0	22.1	1.9	0.9		
	690	2.3	1.3	0.1	0.1		
	700	36.5	20.6	1.5	0.9		
	890	1167.4	778.3	49.4	32.9		
	1100	380.8	280.0	16.1	11.8		
TOTALS		2364.2	1301.8			2.2	1.2
4	100	0.1		0.1			
	120	1.1		0.1			
	130	0.1		0.1			
	150	0.1		0.1			

(continued)

TABLE 47. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
4(Cont)	200	38.4		0.5			
	210	47.4		0.6			
	220	0.9		<0.1			
	250	205.6		2.8			
	290	629.8		8.5			
	340	45.6		0.6			
	350	6.7		0.1			
	370	0.9	0.1	<0.1	<0.1		
	400	100.4	15.7	1.4	0.2		
	480	164.1	53.3	2.2	0.7		
	530	362.8	145.1	4.9	2.0		
	540	0.2	0.1	<0.1	<0.1		
	560	0.8	0.3	<0.1	<0.1		
	620	203.3	101.6	2.7	1.4		
	700	987.8	557.6	13.3	7.5		
	720	274.7	158.8	3.7	2.1		
	750	1555.0	928.9	21.0	12.5		
	800	1214.1	758.8	16.4	10.2		
	1400	1528.9	1216.1	20.7	0.3		
	1800	4.4	3.7	0.1	0.1		
TOTALS		7403.8	3940.3			6.7	3.6
6	100	227.5		0.2			
	110	238.3		0.2			
	120	3.4		<0.1			
	130	40.0		<0.1			
	140	643.4		0.7			
	150	6.8		<0.1			
	160	25.9		<0.1			
	170	386.9		0.4			
	180	28.8		<0.1			
	190	<0.1		<0.1			
	200	205.3		0.2			
	210	56.5		0.1			
	230	9.3		<0.1			
	250	1.4		<0.1			
	260	1401.5		1.4			
	270	158.2		0.2			
	300	1076.9		1.1			
	310	445.7		0.5			
	320	1065.4		1.1			
	330	1972.2		2.0			
	340	6834.4		7.0			
	350	10243.1		10.5			

TABLE 47. (continued)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6(Cont)	370	4218.9	291.0	4.3	0.3		
	380	6068.7	606.9	6.2	0.6		
	390	1139.6	147.0	1.2	0.2		
	400	7683.0	1200.5	7.9	1.2		
	430	2506.6	572.9	2.6	0.6		
	450	3779.4	1021.5	3.9	1.0		
	500	8448.0	3017.1	8.7	3.1		
	530	3959.8	1583.9	4.1	1.6		
	540	2545.1	1051.3	2.6	1.1		
	550	542.1	230.7	0.6	0.2		
	560	1458.6	638.1	1.5	0.7		
	580	206.6	95.0	0.2	0.1		
	600	761.6	366.1	0.8	0.4		
	620	1987.7	993.9	2.0	1.0		
	650	1807.4	951.3	1.9	1.0		
	660	588.0	314.3	0.6	0.3		
	700	956.7	540.0	1.0	0.6		
	710	70.9	40.5	0.1	0.1		
	730	207.3	121.2	0.2	0.1		
	750	748.7	447.0	0.8	0.5		
	760	324.7	195.8	0.3	0.2		
	770	148.1	90.1	0.2	0.1		
	800	30.6	19.2	<0.1	<0.1		
	810	121.9	76.8	0.1	0.1		
	820	997.1	633.3	1.0	0.7		
	910	103.2	69.7	0.1	0.1		
	930	168.0	114.6	0.2	0.1		
	950	94.2	65.0	0.1	0.1		
	1000	349.5	246.9	0.4	0.3		
	1300	32.7	24.8	<0.1	<0.1		
	1400	4102.8	3263.6	4.2	3.3		
	1500	919.2	744.4	0.9	0.8		
	1600	999.5	8219.8	10.2	8.4		
	1700	300.4	250.3	0.3	0.3		
	1720	3096.6	2585.8	3.2	2.7		
	1800	1700.6	1433.6	1.7	1.5		
	2600	340.3	303.8	0.3	0.3		
TOTALS		97580.9	32568.8			88.8	29.7
10	300	63.7		24.5			
	400	196.4	30.7	75.5	11.8		
TOTALS		260.1	30.7			0.2	<0.1

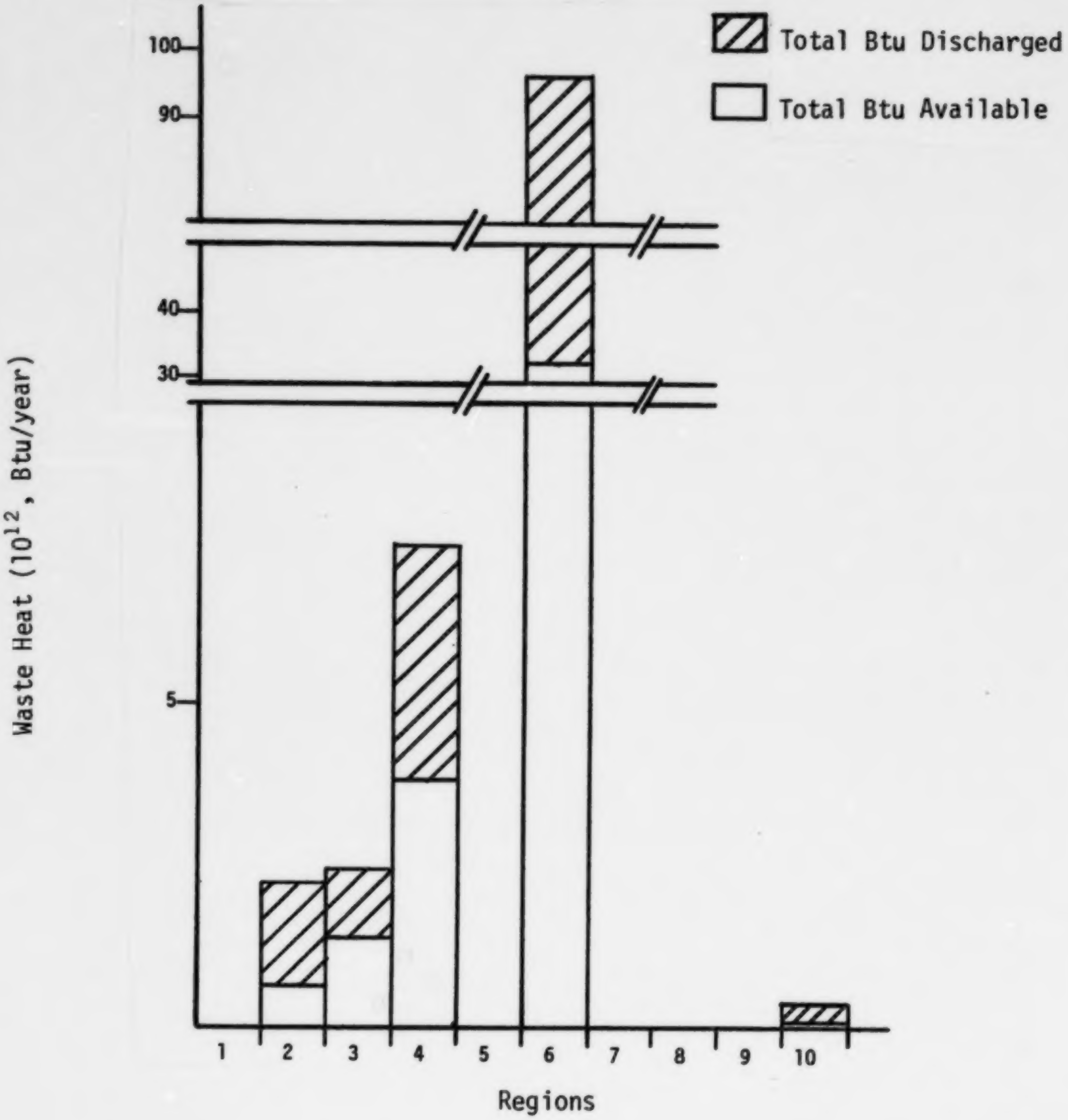

Figure 41. Regional totals for Industrial Organic Chemicals, NEC (flue gases only) (SIC 2869), (1977).

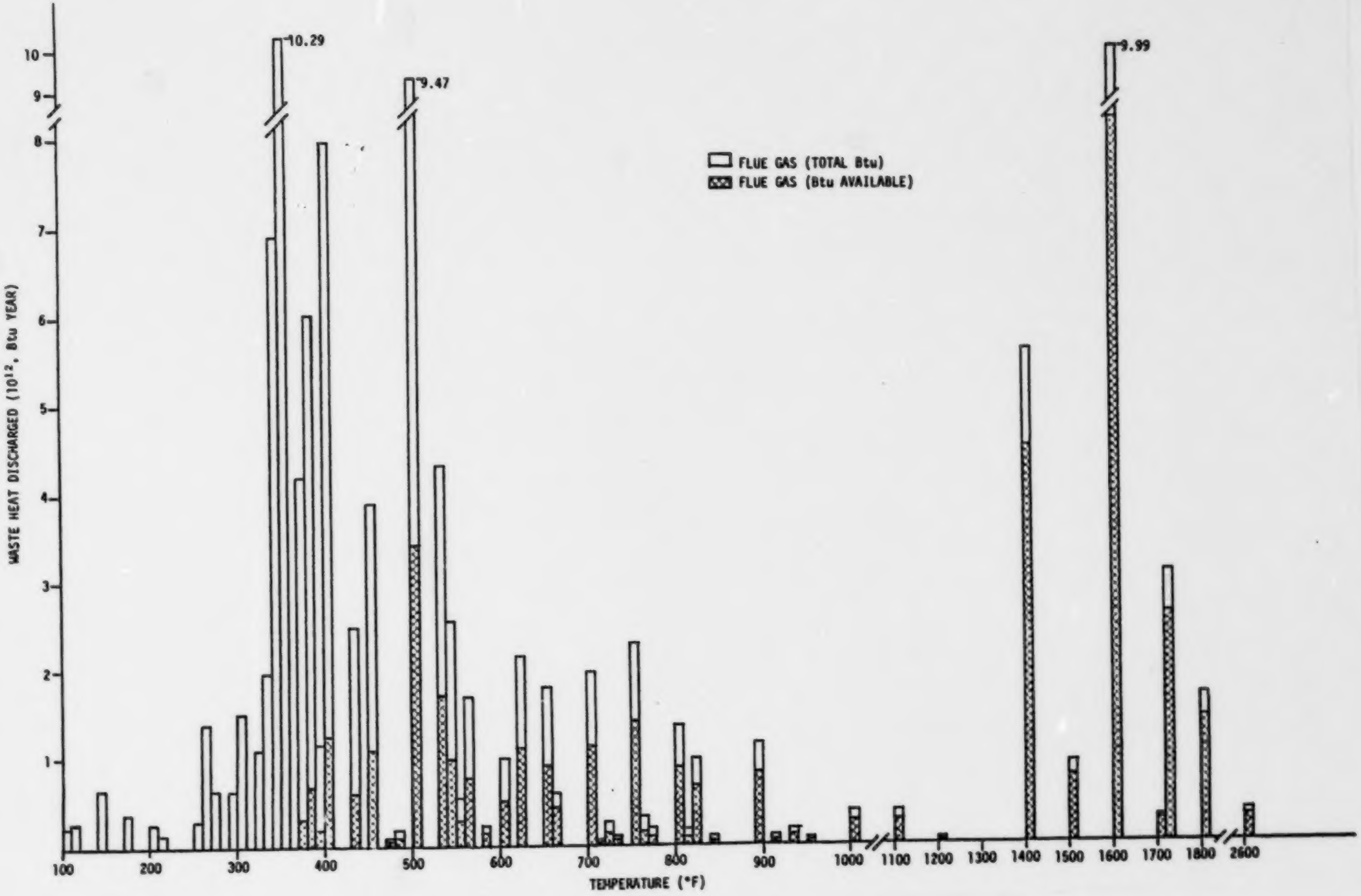

Figure 42. Waste heat temperature profile for Industrial Organic Chemicals, NEC (SIC 2869).

Nitrogenous Fertilizers (SIC 2873)

Ammonia

Ammonia is produced by catalytically reacting nitrogen with hydrogen at high temperatures and pressures. The nitrogen is obtained from air. The source of hydrogen is natural gas, except for minor quantities of chlorine-cell hydrogen and refinery offgas.

Ammonia is produced in greater volume than any other petrochemical. In 1977, there were about 16.5 million tons produced. The main use of ammonia is in fertilizers as liquid ammonia. It is also used for so-called nitrogen solutions, as ammonia nitrate or urea. More than three-fourths of the ammonia chemical manufacturing applications include fibers, plastics, and coating resins through caprolactum, hexamethyline diamine, and crylonitrite. Ammonia is the raw material for nitric acid production, and is used as a refrigerant.

A small amount of ammonia (perhaps 17% of the total) is recovered from coke oven operation, principally as aqua ammonia.

Geographical Distribution

In the United States, there is a heavy concentration of ammonia production along the Gulf Coast, in Texas, Louisiana, and Mississippi. This is because of the availability of intrastate natural gas and because of the availability of low-cost transportation for the product via barge up the Mississippi River or through an ammonia pipeline from New Orleans into the eastern and midwestern states.

Energy Consumption

To produce a ton of ammonia, a typical plant requires 155,000 Btu of electricity and 33 x 10^6Btu of natural gas or fuel oil. Of the fuel required, the feedstock accounts for 20.4 x 10^6Btu per ton. The reformer uses 12.6 x 10^6Btu per ton.

Three and one-half million Btu of the purge gas, from the synthesis loop, is also burnt as fuel for the primary reformer. This energy is considered in the feedstock requirements.

Point Sources of Waste Heat

The major sources of waste heat in ammonia production are: flue gases from the primary and secondary reformers, dryers and coolers, combustion equipment, and other miscellaneous processes; non-contact cooling waters; and process waters for strippers.

All waste heat discharged by process flue gases are tabulated according to temperature ranges and Btu discharged and can be found in Table 48. Therefore, this discussion will focus on waste heat in wastewater discharges.

There are about 15 gallons of boiler blowdown per ton of product. This blowdown has a differential temperature of 220°F and resulted in a waste heat discharge of 27,000 Btu per ton of ammonia produced.

Cooling tower blowdown also results in the discharge of 360 gallons, with a differential temperature of 20°F, per ton of ammonia produced. This stream contains approximately 175,000 Btu of waste heat per ton of product.

There are approximately 300 gallons of stripped process condensate, with a differential temperature of 70°F, for every ton of ammonia produced. This stream contains approximately 175,000 Btu of waste heat per ton of product.

Combined, the wastewaters discharge approximately 4.3×10^{12}Btu annually. This, when compared to the total Btu discharged as process flue gases, indicates that these wastewater streams account for nearly 15% of the total discharged heat in ammonia production. This is equivalent to only 1.4% of the fuels and electricity purchased by SIC 2873.

Discussion - Tables and Graphs

The total flue gas waste heat discharged by SIC 2813 is presented in Table 48. This indicates that only 8.25% of the purchased fuels and electricity was discharged as waste heat. Approximately one-fourth of this energy was discharged at temperatures greater than 350°F.

Table 49 presents a regional breakdown of the flue gas waste heat discharged. This table indicates that EPA region 6 accounts for 72% of the total waste heat discharged by this industry. This data is further summarized in Figure 43.

The flue gas waste heat temperatures profile for this industry is presented in Figure 44. This figure indicates a fairly evenly distributed profile.

TABLE 48. TOTAL WASTE HEAT DISCHARGED BY NITROGENOUS FERTILIZERS (SIC 2873)

② IPP #	DESCRIPTIONS	Temperature Range (°F)	Total Btu (x 10^9)	Total Btu Available (x 10^9)	% Btu Available	%Waste Heat ①
	Flue Gases					
BL	Process, NEC	100-940	7325.62	2298.68	31.38	2.36
1	Dryers & Coolers	100-700	3588.19	927.17	25.84	1.16
3	Dryers & Coolers	400-450	571.96	111.80	19.55	0.18
4	Granulator	130	1453.47	0.00	0.00	0.47
00	Combustion, NEC	100-700	12638.29	3603.50	28.51	4.08
	Total Flue Gases	100-940	25577.53	6941.15	27.14	8.25

① Based on purchased fuels & electricity

② NEDS data, EPA/2-76-005 OAQPS guidelines

TABLE 49. REGIONAL WASTE HEAT DISCHARGED BY NITROGENOUS FERTILIZERS (SIC 2873)

EPA REGION#	TEMP. (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
1	400	68.5	10.7	100	15.6		
TOTALS		68.5	10.7			0.3	0.1
3	100	5.1		40.5			
	180	7.5		59.5			
TOTALS		12.6					
4	100	41.1		2.6			
	120	1.3		0.1			
	140	29.5		1.9			
	150	21.6		1.4			
	200	31.9		2.0			
	230	16.5		1.1			
	240	115.3		7.3			
	300	12.5		0.8			
	400	725.2	113.3	46.2	7.2		
	450	435.5	117.7	27.7	7.5		
	490	77.1	26.3	4.9	1.7		
	520	62.5	24.2	1.7	1.5		
TOTALS		1570.0	281.5			6.1	1.1
5	210	16.3		100			
TOTALS		16.3				0.1	
6	100	242.6		1.3			
	110	4.2		<0.1			
	120	167.1		0.9			
	130	34.6		0.2			
	140	16.1		0.1			
	170	15.4		0.1			
	180	641.9		3.5			
	200	0.9		0.1			
	210	31.5		0.2			
	230	193.7		1.0			
	240	4.4		<0.1			
	280	167.9		0.9			
	300	823.5		4.5			
	320	366.8		2.0			
	340	1060.8		5.7			
	350	66.1		0.4			
	400	482.0	75.3	2.6	0.4		
	430	1404.0	320.9	7.6	1.7		
	450	1159.6	313.4	6.3	1.7		
	460	1147.3	332.1	6.2	1.8		

(continued)

TABLE 49. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9 Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
6(Cont)	470	577.5	177.7	3.1	1.0		
	500	2127.6	759.8	11.5	4.1		
	510	1285.4	478.3	7.0	2.6		
	520	156.0	60.3	0.8	0.3		
	540	1432.0	591.5	7.8	3.2		
	550	149.9	63.8	0.8	0.3		
	600	14.1	6.8	0.1	0.1		
	640	446.3	231.1	2.4	1.3		
	660	701.7	375.1	3.8	2.0		
	670	769.9	417.6	4.2	2.3		
	700	2745.2	1549.7	14.9	8.4		
	940	28.1	19.3	0.2	0.1		
TOTALS		18464.0	5772.6			72.2	22.6
7	110	42.2		2.3			
	120	20.5		1.1			
	130	1436.1		77.8			
	150	0.8		0.1			
	210	32.7		1.8			
	230	1.8		0.1			
	250	12.5		0.7			
	300	77.1		4.2			
	400	58.0	9.1	3.1	0.5		
	450	5.2	1.4	0.3	0.1		
	470	29.0	8.9	1.6	0.5		
	620	131.0	65.5	7.1	3.5		
TOTALS		1846.9	84.9			7.2	0.3
8	460	159.5	46.1	100	28.9		
TOTALS		159.5	46.1			0.6	0.2
9	130	263.2		22.9			
	320	491.4		42.7			
	340	129.3		11.2			
	550	210.9	89.7	18.2	7.8		
	580	57.0	26.2	4.9	2.3		
TOTALS		1151.8	115.9			4.5	0.5
10	110	38.5		1.7			
	240	114.5		5.0			
	250	63.0		2.8			
	270	3.1		0.1			
	350	50.5		2.2			
	370	317.5	21.9	13.9	1.0		

TABLE 49. (continued)

EPA REGION#	TEMP (°F)	TOTAL WASTE HEAT (10^9Btu/YEAR)		PERCENTAGE OF TOTAL REGIONAL WASTE HEAT		PERCENTAGE OF TOTAL SIC WASTE HEAT	
		DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE	DISCHARGED	AVAILABLE
10 (Cont.)	380	22.8	2.3	1.0	0.1		
	390	24.9	3.2	1.1	0.1		
	420	926.7	190.8	40.5	8.3		
	470	33.8	10.4	1.5	0.5		
	670	388.4	210.7	17.0	9.2		
	800	304.2	190.1	13.3	8.3		
TOTALS		2287.9	629.3			8.9	2.5

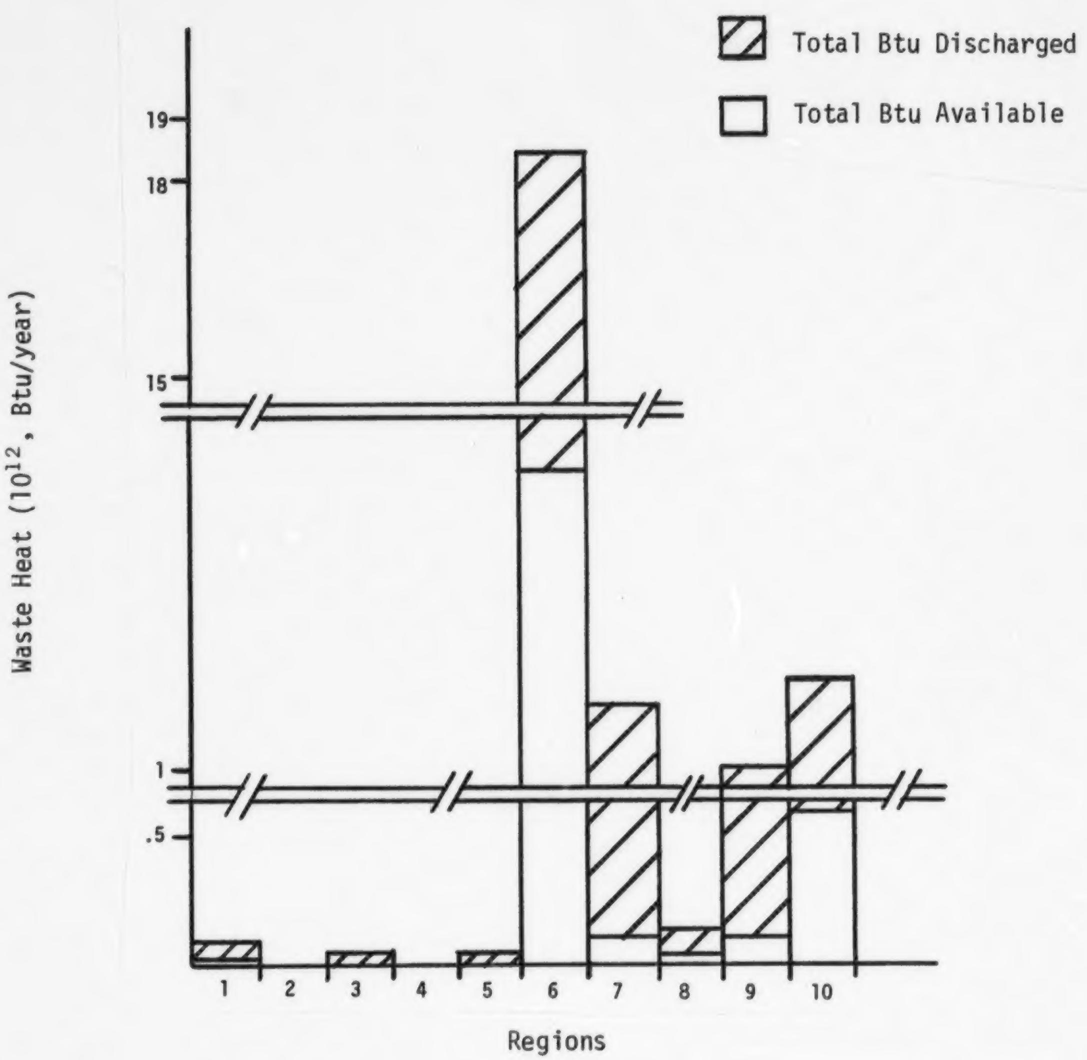

Figure 43. Regional totals for Nitrogenous Fertilizers (SIC 2873), (1977).

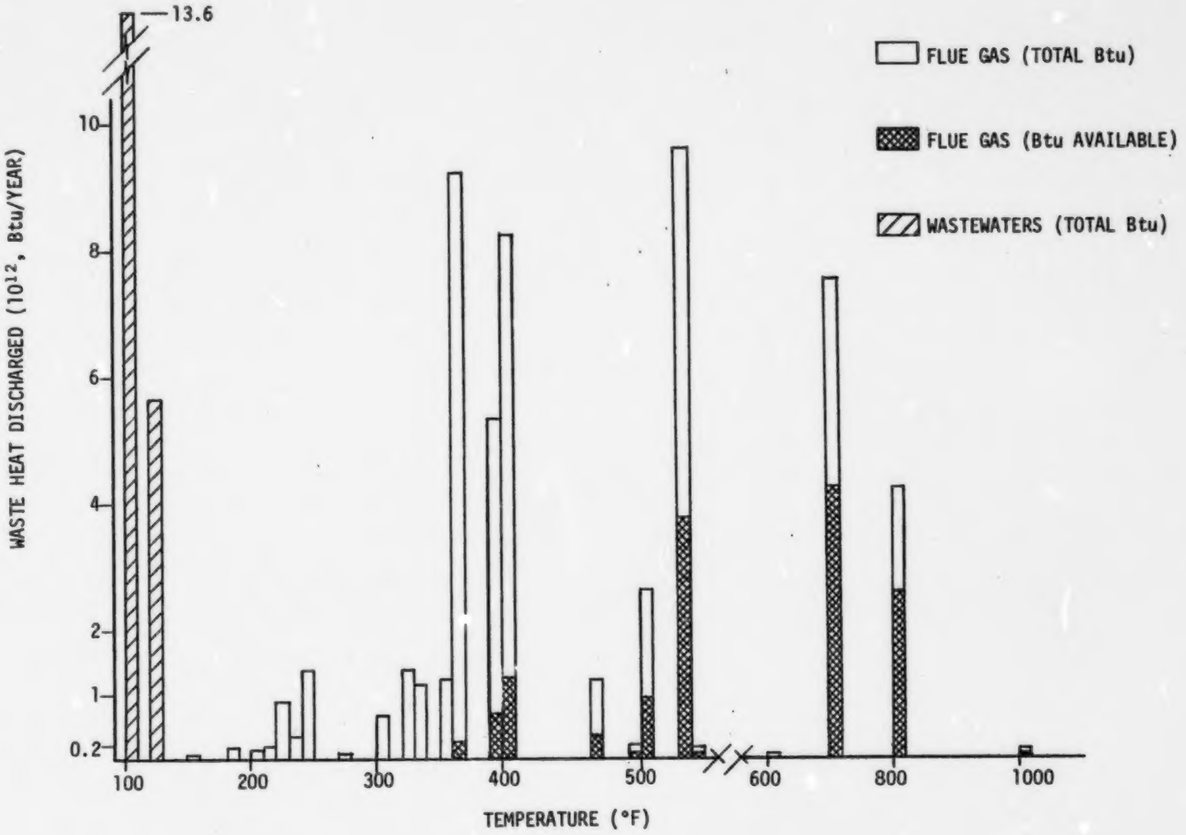

Figure 44. Waste heat temperature profile for Nitrogenous Fertilizers (SIC 2873).

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SECTION 8

EMERGING TECHNOLOGIES FOR ENERGY DEVELOPMENT

COAL CONVERSION

Introduction

The desire of the United States to achieve a status of energy "self sufficiency" dictates that a replacement be found for the ever increasing quantities of oil and natural gas that are being consumed each year. During the period from 1956 to 1973, the contribution of oil and gas to the total energy supply increased from 67% to 75%. Nearly all of this growth has been at the expense of this nation's most abundant but environmentally less acceptable fuel, coal. Known coal reserves exceed 3,000 billion tons. The total combined heating values of oil, gas, oil shale, coal and current nuclear fuels offer 35.8×10^{15}Btu of energy potential, whereas coal alone offers 32.0×10^{15}Btu, or about 90% of this quantity. Consequently, coal conversion plants offer one short-term solution to our energy problems and must be considered as part of the fuel technology of the United States.

However, the environmental impacts of coal conversion plants are potentially quite sizable and, in order to avoid simply transferring the environmental impact of coal utilization from existing facilities to these emerging technologies, an early and careful assessment of the environmental aspects of coal conversion processes is required. Most of the processes reviewed during this project were in various phases of demonstration and development. It must be realized that the purpose of these facilities was to demonstrate system feasibility and, as such, were usually not designed for maximum thermal efficiencies. Therefore, it is anticipated that as commercial size plants become a reality, the thermal efficiencies of these processes may increase substantially.

The coal conversion processes currently undergoing development range in overall efficiencies from a low of 38% for certain coal liquefaction process to a high of 80% for low Btu gas synthesis processes. This overall efficiency is defined as the heating value of the refined fuel products divided by the heating value of the coal feedstock. This indicates that from 20% to 62% of the heating value of the feedstock, or as much as 163% of the value of the refined fuel product, is rejected into the environment. If energy "self sufficiency" is to be realized, it could be assumed that imported fuels would be replaced by domestically converted fuels from coal. During 1976, the United States imported 1.9×10^9 barrels of crude oil. This represents over 40% of the domestic consumption. If a nominal fuel conversion efficiency of 67% is assumed for coal conversion processes, the heat rejected from fuel conversion plants would equal 3.2×10^{13}Btu/day, or 1.1×10^{16}Btu/year.

The objective of coal conversion processes is to increase the hydrogen to carbon ratio and to remove undesirable materials. Coal has a hydrogen to carbon ratio below one. This ratio may be increased by either adding hydrogen or removing carbon. Generally, liquefication processes increase this ratio to about two, whereas gasification processes increase it to about four.

In general, four distinct conversion routes are possible; pyrolysis, in which the coal is heated to break it down into solids, liquids, and gases; solvation, where the coal is dissolved and, with the addition of small amounts of hydrogen, can be filtered and converted into an essentially ash and sulfur-free solid or liquid; hydrogenation, in which coal and hydrogen are reacted directly; and synthesis gas (carbon monoxide and hydrogen) production, in which coal is reacted with an oxidizing agent and steam.

The nature and quantity of the products of these methods depends upon the properties of the coal feedstock as well as the process conditions. An example of this dependency can be seen in hydrogenation reactions, where if this process is performed at 550°F in the presence of a catalyst and at elevated pressures, a liquid product can be made. Whereas, if a catalyst is not present, the coal can react directly with hydrogen at even higher temperatures (1500°F to 1800°F) and pressures to produce methane.

This dependence has fostered the development of a rather impressive number of techniques and processes for coal conversion. One source has compiled information on over 100 major processes for coal conversion, which are in various stages of development.

Thermal Fuel Conversion Efficiency

The thermal fuel conversion efficiencies represent a ratio between the total heating value of the refined product and the total heating value of the feedstock. It identifies the quantities of environmentally less acceptable fuels that are consumed to produce an environmentally acceptable fuel. The heating value of the fuel which is consumed must necessarily be discharged to the environment as waste heat. These losses are the result of:

- Sensible heat of the product
- Process and cooling water streams
- Radiant heat transfer
- Air cooling of equipment
- Heating value of char

The thermal fuel conversion efficiencies of the various processes presently in commerical use, or in the later stages of development, vary considerably due to the following variables.

- The specific nature of the feedstock
- The degree of waste heat utilization
- Mode of process operation (whether air or oxygen is used in the gasifiers)
- Combustion or gasification of filter cake
- Processes used for hydrogen generation
- Processes utilized for by-product recovery
- Whether an energy audit includes all by-products

Because of these variables, it was necessary to select various specific coal conversion processes and review their thermal efficiency in detail.

Gasification

There are, at present, four gasification units which have attained a commercial status. These technologies differ considerably in size, approach to gasification, and end product fuels. They are the Wellman-Galusha reactors, the Koppers-Totzek, the Lurgi gasifiers, and the Winkler Process. The following efficiencies reported for these processes imply the amount of Btu delivered to the customer in gas form, expressed as a percentage of the initial feedstock's BTU content, and any additional energy import for gasifier operations. Low and medium Btu gas calculations were made by including sensible heat, tars, and volatiles in the coal gas energy. These efficiencies were also developed using only the calorific content of the gas. Methanation schemes only include the calorific value of the gas, since synthesis gas must be cooled and cleaned before undergoing the shift reaction and methanation.

Lurgi Gasifier

The Lurgi Gasifier may utilize either air or oxygen along with steam as feeds to the coal reactor. Both units are modified fixed-bed pressurized reactors, while oxygen has been chosen when the product gas is to be methanated. Lurgi gasifiers, operating in an air-blown mode, offer a hot gas efficiency of 79.6% (exclusive of the energy contained in the gas pressure). The lower heating value, including some sensible heat regained through heat exchangers, was reported as 70.2%. Operation in the oxygen blown mode (as in production of raw gas for synthesis into methane) produced efficiencies of 66.6% (including the export of by-products). This value was based on the El Paso Natural Gas project, which is discussed in further detail in subsequent sections. It should be noted, however, that this value reflects the incorporation of the Lurgi gasifier into an integrated complex where heat generated in exothermic reactions may be utilized in endothermic reactions. The efficiency of the gasifier itself has been reported as only 60%.

Several other systems have been suggested which allow for greater overall efficiency of the Lurgi gasifier. Operating the Lurgi air-fed reactor, in connection with a combined-cycle-electricity-generating unit, capitalizes on the energy inherent in the gas pressure. J. Agosta and Associates note the volume of low Btu gas that will produce 493 Mw from a conventional electricity plant will generate 534 Mw from a combined-cycle operation. This represents an end-use efficiency increase of 14%; some of this increase comes from the electricity plant's ability to use the pressure, and the rest comes from the energy inherent in the gas pressure.

Based on the design of the Lurgi Dry Ash Gasification process for the El Paso Natural Gas Company, a total of about 501,000 Btu of waste heat would be discharged to the environment for every 1,000,000 Btu of products produced. Since this complex was designed not to produce any aqueous effluent, the thermal discharges to the environment must either be steam, cooling water, flue gases, or ash. Approximately 18% of the total waste heat is discharged to non-contact cooling waters or a total of 91,590 Btu per million Btu of product gas. This cooling water is reported to have a differential temperature of 180°F with a flow rate of 0.42 GPM per million Btu of product gas produced. Radiation heat losses for this complex were estimated at 10% of the feedstock energy, which corresponds to about 150,000 Btu per million Btu of product gases. The remaining waste heat exits via the ash and flue gases and accounts for about 260,000 Btu per million Btu of produced gas.

Koppers-Totzek Gasifier

This gasifier is a refractory lined, horizontal, cylindrical vessel with conical ends. Oxygen, steam and coal react at about atmospheric pressure and 3,300°F. Fixed carbon and volatile matter are gasified to produce offgas containing carbon monoxide and hydrogen. Coal ash is converted into molten slag, a portion of which drops into a waterquench tank, the remainder is carried by the gas. Low pressure steam is circulated around burners and refractory to cool them as well as producing process steam. Gas leaving the gasifier is quenched with water to solidify entrained molten ash. After passing through a waste heat boiler, the gas is scrubbed to remove entrained solids. Scrubbed gas is compressed to 450 psig. Hydrogen sulfide and a controlled quantity of carbon dioxide is removed by purification. The purified gas is then shifted and methanated. The methanated gas is then dehydrated and purified to remove carbon dioxide. Dry, pulverized coal of any type may be used.

The Koppers-Totzek reactor, operating in an industrial gas production mode, offers a higher heating value efficiency ranging from 85%, when operated on Illinois coal, to 90.3% when gasifying eastern bituminous coal. The efficiency range is from 83% to 89% when the calorific value plus the sensible is calculated, but the energy contained in the water vapor element of the product gas is discarded. When only the calorific value plus the sensible heat gleaned in a recuperator (waste heat recovery system) is available for utilization, the efficiencies are as follows: eastern bituminous coal, 75.2%; Illinois coal, 74%; and western coal, 75.5%. These are the efficiencies of burning cooled, cleaned, gas, and do not include energy values for the compression of the product to pipeline pressure. Other sources have reported a base thermal efficiency for a Koppers-Totzek gasifier, producing gas at 150 psig, of 61% with this value increasing to 69% if the product gas is only compressed to 15 psig.

Based on a thermal efficiency of 61%, an estimated 642,000 Btu of waste heat would be discharged to the environment for every million Btu of products produced. About 73% of this waste heat is discharged via wet cooling towers resulting in evaporation losses of approximately 0.3 GPM per million Btu of products. This non-contact cooling water has an estimated differential temperature of 23°F, and a flow rate of 1.7 GPM per million Btu produced. This corresponds to about 466,500 Btu per million Btu produced. Radiation losses have been estimated at 164,500 Btu per million Btu produced, with stack losses approximately 10,900 Btu per million Btu produced.

Wellman-Galusha Gasifier

This gasifier is a relatively small unit with a maximum capacity of only 85 tons of coal per day. This size precludes its use in SNG operations, making it primarily an Industrial System. In the Wellman gasifier, coal is fed into the top of the reactor where it proceeds through drying, pyrolysis, and coking, before finally reaching the combustion zone where it is fired with minimal quantities of air. In this countercurrent flow, the hot gases rise against the flow of the coal. This configuration minimizes thermal efficiencies but generates large volumes of tars and reduces the rate of gasification.

The Wellman reactor operates at one of the highest thermal efficiencies in the industry. When the sensible heat plus the tars and volatiles are employed by the gas user, efficiencies of 92% may be achieved. However, when gases produced by the Wellman unit are cooled and cleaned prior to combustion the efficiency decreases to 75%.

With a thermal efficiency of 75%, a total of approximately 333,000 Btu of waste heat would be discharged to the environment for every million Btu of products produced. Since detailed data on the cooling water system was not available, it was assumed that the heat rejection system utilized would be discharged via cooling waters through mechanical draft towers with large differential temperature (25°F to 35°F) and approaches over 10°F. Based upon these assumptions, about 183,000 Btu of waste heat would exit via the cooling towers resulting in the evaporation of approximately 0.01 gallons per million Btu of products produced. Radiation losses were estimated at about 133,000 Btu per million Btu of products with stack gas losses corresponding to about 17,000 Btu per million Btu of products produced.

Winkler Process

The Winkler process utilizes a fluidized bed gasifier with oxygen and steam used as the gasifying media. The coal reacts with the oxygen and steam to produce an offgas rich in carbon monoxide and hydrogen. Because of the high temperatures, all tars and heavy hydrocarbons are reacted. About 70% of the ash is carried over by the gas and 30% is removed from the bottom of the gasifier by the ash screw. Unreacted carbon, carried over by gas, is converted by secondary steam and oxygen in the space above the fluidized bed. To prevent ash particles from melting and forming deposits in the exit duct, this gas is cooled by a radiant boiler section before it leaves the gasifier. Raw gas leaving the gasifier is passed through a further waste heat recovery section. Fly-ash is removed by cyclones, wet scrubbers, and an electrostatic precipitator. Gas is dehydrated and compressed to pipeline quality.

The thermal efficiency of the Winkler Process has been reported at 66.8%. Based on this value, a total of approximately 500,000 Btu of waste heat would be discharged to the environment for every million Btu of products produced. Assuming conventional industrial process cooling trends, about 275,000 Btu of waste heat would exit the system via non-contact cooling waters, with a differential temperature around 30°F. Radiation losses would be about 150,000 Btu and stack gases accounting for about 73,000 Btu of waste heat for every million Btu of products produced.

Hygas

The Hygas process is one of two large pilot plant coal conversion projects which have been constructed under contract with the Office of Coal Research (OCR). Hydrogen (produced in another process step) is reacted directly with coal at 1,000 to 1,500 psig to make a high Btu gas. The hydrogasifier is operated in a counter-current fashion with coal being fed into the top, and hydrogen at the bottom. It consists of two fluid beds in series; the upper bed is operated at about 1,200°F and the lower bed at 1,700°F. Operating in this fashion optimizes the process with respect to reaction rate and the amount of methane at equilibrium in the product gas. The easily gasified part of the coal reacts in the upper zone, the more refractory portion in the lower zone, and the most refractory part of the coal is removed and used to prepare the hydrogen for the hydro-gasification reaction.

Several different methods for the production of the hydrogen required for this process are presently undergoing further research and development. The final selection of the hydrogen production method will have a significant effect on the thermal efficiency of the total complex. However, it is anticipated that the thermal efficiency will be about 68% and that conventional process cooling practices will be utilized.

CO_2 Acceptor Process

This is the second of the two fully constructed OCR supported large pilot plants for producing high Btu gas. This process makes synthetic natural gas (SNG) from lignite by gasifying it in a fluidized bed with steam at temperatures around 1,500°F and at 150 psig. In this process, dolomite (preheated to 1,900°F in a regenerator vessel and calcined) is fed into the top of the gasifier where it is devolatilized. The char is then reacted with steam and hot dolomite. The dolomite provides the reaction heat in two ways; by the sensible heat it brings into the gasifier from calcination, and by the heat released during a unique chemical reaction in which calcined dolomite absorbs carbon dioxide exothermically. The spent dolomite and the unreacted char are circulated to a regenerator where the dolomite is recalcined using heat produced from the combustion of the char. The gases released by heat and chemical reaction between the steam and coal contain all of the ingredients needed for subsequent methanation to pipeline gas.

In determining the thermal efficiency of this process, a hypothetical value of 68.5% may be obtained by dividing the total product heating value by the heating value of the coal fed to the degasifier. However, this does not account for fuel being fired in the drying and preheating of the lignite. If product gas taken prior to methanation is used for this purpose, the thermal efficiency of the process decreases to 60.2%. In practice, however, it was expected that a blend of both product gas and lignite would be used for this purpose. The composition of this blend would be 75% lignite and 25% low sulfur, low Btu gas. This would meet the allowable emissions of 1.2 lbs of SO_2 per million Btu fired. This mode of operation would yield a thermal efficiency of 61.7% and based on reported values, would release a total of approximately 620,000 Btu of waste heat to the environment for every million Btu of products produced. Reportedly, only 9.5% of this waste heat exits via noncontact cooling waters. This corresponds to about 1.8 gallons per million Btu of products, with a differential temperature of 28°F. Radiation losses were taken as 10% of feedstock energy which corresponds to about 162,000 Btu/million Btu of products. The remainder of the waste heat (about 400,000 Btu/million Btu of products) exists via stack gases and contact process streams. This process is generally proposed for the production of SNG. It may alternately be utilized in the production of a low Btu clean fuel gas. The thermal efficiency for such a process is 76%.

Synthane Process

The Synthane Process, which is being developed by the Bureau of Mines, is an intrinsically high efficiency fluidized bed coal gasification system operating at commercial pipeline pressure (1000 psig) and designed to produce a high Btu content product gas. Gasification is accomplished in the presence of steam and oxygen. The heat required for the gasification is supplied by the reaction of oxygen with a portion of the coal. The high pressure operation of this process favors methane yield, minimizes gasifier volume, reduces oxygen requirements, and reduces product gas compression.

The thermal efficiency of the Bureau of Mines Synthane Design Basis is reported as 63.5%. This figure includes a credit for the tars produced of 3.9% as well as 0.3% for sulfur recovery. It should be mentioned, however, that there are several opportunities in the proposed system which a designer should consider for energy recovery.

A review of the effect of these modifications on the overall thermal efficiency of the process indicated that, depending upon the degree of utilization of these modifications, a thermal efficiency of from 60.0% to 66% may be realized. The characteristics of the waste heat discharged to the environment by this process, with an assumed thermal efficiency of 63.5%, are summarized in Table 50.

In addition to the process previously discussed, there are several others which are undergoing various phases of research and development. The BIGAS unit is one such process which is undergoing extensive development work in order to provide design data for construction of a commercial plant. The thermal efficiency of this unit has been estimated to be about 67%.

TABLE 50. WASTE HEAT DISCHARGES OF COAL CONVERSION PROCESSES

PROCESS	THERMAL EFFICIENCY %	TOTAL WASTE HEAT BTU's[1]	WASTE HEATE TO COOLING WATER BTU's[1]	ΔT OF COOLING WATER °F	COOLING WATER REQUIREMENTS GPM[2]	EVAP. LOSSES GPM[2]	RADIATION LOSSES BTU's[3]	STACK GAS & PROCESS WASTE BTU's[1]	% WASTE HEAT TO COOLING WATERS
Lurgi	66.6	501,502	91,593	18[4]	0.423	0.006	150,150	259,758	18.3
Koppers-Totzek	61.0	641,931	466,483[6]	23	1.68	0.029	164,598	10,850	72.6
Wellman-Galusha	75.0	333,250	183,287[6]	30[7]	0.51	0.011	133,333	16,630	55.0
Winkler	66.8	497,006	273,353[6]	30[7]	0.76	0.017	149,700	73,953	55.0
Hy-Gas	68.0	470,588	258,824[6]	30[7]	0.72	0.016	147,058	64,706	55.0
CO_2- Acceptor	61.7	620,744	58,931[5]	28	1.84	0.039	162,074	399,739	9.5
Synthane	63.5	574,802	377,786[5]	30	1.05	0.027	157,480	39,536	65.7
Low Btu Gas Synthesis	80.0[8]	250,000	137,500[6]	30	0.38	0.008	62,500[9]	50,000	55.0
Berguis	55.0	818,181	450,000[6]	30	1.25	0.028	181,818	186,363	55.0
Fisher-Tropsch	38.0	1,631,840	897,512[6]	30	2.49	0.056	263,158	471,170	55.0
COED Process	72.2	385,042	211,773[6]	30[7]	0.59	0.013	138,504	34,765	55.0
H-Coal	75.2	329,787	181,383[6]	30[7]	0.50	0.011	132,978	15,426	55.0

[1] Reported values are Btu's per 10^6 Btu's of products.

[2] Reported values are GPM per 10^6 Btu's of products.

[3] Radiation losses @ 10% of feedstock energy.

[4] Actual reported value.

[5] Based on rept. evaporation losses from cooling tower.

[6] Assume 55% of waste heat exits via cooling waters.

[7] Assumed 30°F ΔT

[8] Values reflect an assumption that low-Btu gas synthesis processes would be developed with thermal efficiencies of 80%

[9] Radiation losses @ 6% of feedstock energy.

The U-Gas is another such process, developed by the Institute of Gas Technology, for the production of energy for conventional and industrial power generation as well as for combined-cycle power generation. Reported thermal efficiencies for this process range from a low of 43% to around 68%.

Low Btu Gas

The process steps involved in the manufacture of low Btu gas from coal are similar to those utilized in the production of high and medium Btu gases. The gasification steps are often identical with the substitution of air for the oxygen used in the production of high Btu gas. The product gas is diluted with the nitrogen in the air, producing a gas with a heating value of from 135 to 200 Btu/SCF, depending on how much of the gases distilled from the raw coal are retained in the product gas.

The production of low Btu gas is both less complicated and less expensive than making the high Btu gas. The shift conversion is not needed and because there is no need for cleaning the gas to protect the methanation catalyst, a much simpler gas cleaning system is required. Since the methanator is also eliminated the overall thermall efficiency increases significantly.

A large difference presently exists between the state of development of high Btu and low Btu gasification processes. The development of high Btu gas conversion technologies was started at an early date by the gas transmission and distribution companies who felt that supplies of indigenous gas would be insufficient to keep their pipelines operating at a high capacity. They needed a substitute natural gas, not just a clean gas from coal, since the cost of transporting and distributing low Btu and even medium Btu gas would require replacement of millions of gas burners. These companies were willing to support a high Btu gas at an early date. Consequently, there has been little research on processes to make clean, low Btu gas from coal using air as an oxidant. Because of this, insufficient data was available for determining the overall thermal efficiencies of the specific processes. However, since the production of low and medium Btu gas does not require methanation and the associated desulphurization and cooling, radiation losses were only estimated at 5% of the feedstock energy and it is felt that overall thermal efficiencies of 80% could be achievable in commercial applications. The characteristics of the waste heat discharged to the environment are summarized on Table 50.

Liquefication

Liquefication is the conversion of solid coal into a liquid hydrocarbon by the process of a hydrogenation to depolymerize the coal molecules. In the past, extensive research into liquefication processes was conducted in Germany. This technology has fostered the development of two processes which were not used commercially. Until recently, however, liquefaction research was concentrated on producing a substitute refinery feedstock. More recent efforts are being directed toward obtaining the maximum quantity of low cost clean fuel substitute, which is suitable for direct use in boilers.

The Bergius Process

The Bergius Process is one of the two processes used industrially during World War II. This route produced about 85% of all synthetic liquid fuels made in Germany. It is a hydrogasification reaction. Coal is first ground to a fine size and mixed with a hydrocarbon liquid, which has been produced by the process itself, and with a catalyst. This mixture is reacted with hydrogen (produced by gasification of coal) at 10,000 psig at 850°F. The products from the first reactor are separated into light, middle and bottom fractions. The middle fraction is further treated over a catalyst in a vapor phase and under relatively mild conditions to produce petroleum-like products. The bottom fraction is filtered to remove solids (unreacted coal, catalyst, ash) and the remaining liquid is used to mix with the fresh coal being processed in the first reactor.

The extreme operating conditions in the primary reactor (resulting from the poor quality of the catalysts available) and the large volume of hydrogen consumed, which was expensive to produce from coal using existing technology, made the liquid products very expensive. Overall process efficiency was about 55%. No commercial Bergius plants are currently operating, but it was anticipated that current industrial process cooling trends would be utilized and that 55% of the waste heat would exit via the cooling towers. The specific nature of the waste heat streams are summarized on Table 50.

Fisher-Tropsch Process

The Fisher-Tropsch Process was the other process used by the Germans to produce industrial quantities of synthetic hydrocarbon liquids. It is a synthesis gas process. The major difference in the products resulting from the Bergius and Fisher-Tropsch process was paraffinic (with cobalt catalyst) or highly olefinic (with iron catalysts).

Coal is first gasified completely to synthesis gas. The ratio of the hydrogen to carbon monoxide can be adjusted to produce different final products for use with different types of catalysts. The purified gas is passed over a catalyst at temperatures of 570°F to 640°F at pressures of about 450 psig. A mixture of straight-chain paraffinic and olefinic products are made that can be further refined to give synthetic liquid fuels.

While the Fisher-Tropsch Process, as used in Germany, avoids the extreme processing conditions of the Bergius method, the complete gasification of coal and its reconstitution to liquid products give an overall conversion efficiency of only 38%. The nature of the waste heat streams discharged by this process are summarized on Table 50. However, it should be noted that it is unlikely that this process would achieve widespread commercial utilization unless further means of increasing the thermal efficiency were incorporated into the design of the complex.

Coed Process

This process produces a liquefied product which is suitable for use as a refinery feedstock. The process is basically a pyrolysis method aimed at removing valuable liquids from the coal before it is burned. The amount of liquid and char produced will vary with both the quality of coal used and processing conditions necessary to optimize liquid yields. Typically, four stages operating at 600°F, 850°F, 1000°F, and 1600°F were used. Heat for the process is generated by burning char in the fourth stage and by using the hot gases and hot char to supply the heat for the other stages. Some medium Btu gas is produced during the carbonization, but the two major products are a hot char and liquids. The oil is filtered to remove solids and hydro-treated to make a synthetic crude oil. Hydro-treating tests have been conducted with favorable results. The overall thermal efficiency of this process has been reported at 72.2%. The nature of the waste heat streams is presented on Table 50.

H-Coal Process

This process has been under study by Hydrocarbon Research, Inc., and is a modification of the H-Oil process of catalytic hydrogenation.

Coal is mixed with a recycle oil and fed into a hydrogenator containing a granular catalyst of cobalt molybdate, which is maintained in an embulient state by the flow of the liquid-solid mixture and hydrogen. The product is first treated in a hot atmospheric flash drum and the bottoms stream is further treated to produce a bottoms slurry product, a portion of which is used for the recycle stream.

A high yield of low-sulfur liquid is produced which is suitable for a refinery feedstock or a low-sulfur boiler fuel. The overall thermal efficiency of this process has been reported at 75.2%.

SHALE OIL

The United States' interest in oil shales has stemmed from an obvious problem, crude oil shortages. In order for the United States to achieve self-sufficiency, we must find an alternative fossil fuel for our energy needs. No fossil fuel can offer a long range solution, but coal offers a midrange solution until new energy technologies can alleviate the need for fossil fuels. However, conversion to coal will take time and while we learn how to apply coal to fill our variety of energy uses, we must supply our current needs. This means that petroleum resources must be further exploited. Hence, oil shales may play an important part in helping meet our present needs.

Geologically speaking, oil shale is not a shale and it contains virtually no oil. It is a finegrained, compact, laminated, sedimentary rock that contains kerogen, and organic high molecular weight mineraloids.

When heated, kerogen yields hydrocarbon liquids, ranging typically from 10 to 60 gallons per ton of shale, which are akin to natural crude oil and can be refined much the same way. A typical oil shale contains about 15 wt% kerogen and 85 wt% of carbonates, feldspars, quartz and clays:

Kerogen Content	15 wt%
Carbon	80.5
Hydrogen	10.3
Nitrogen	2.4
Sulfur	1.0
Oxygen	1.5
Mineral Content	85 wt%
Carbonates	48
Feldspars	21
Quartz	15
Clays	13
Analcite and Pysite	3

Geographical Distribution

In the United States, oil shale deposits occur in a great many states, the most prominent being: Colorado, Utah, Wyoming, Montana, California, Alaska, Texas, Oklahoma, and Arkansas.

Although oil shale deposits are found in numerous areas of the United States, the Green River formation is at present the only deposit of adequate size and availability to have potential commercial value. Of these, the Piceance Basin deposits are considered to be of prime importance. The Green River formation encompasses about 17,000 square miles and has an in-place oil potential that has been estimated to be at least 2 x 10^{12}barrels. At our current national oil consumption rate of about 18 million barrels a day, the Green River Formation represents about 300 years of in-place oil. It has been estimated that about 85 billion barrels of the total in-place reserves could be recovered with today's mining technology. Thus, about a 12 year national supply of oil could be recovered without requiring any technological break-throughs in mining methods. As mining technology advances, it can be expected that more of these in-place reserves will be recoverable, including those in the other United States oil shale deposits.

Process Alternatives

In order for a retorting operation to be economically attractive, it must be self-supporting as far as energy requirements are concerned. Generally the most feasible process is to derive the heating requirements from some of the various products of the pyrolysis, using a minimum of the valuable products of the process. Another area of consideration is the possible method of transferring heat to the solid material and the recovery of heat not actually utilized in the process itself, utilizing the principles of countercurrent heat exchange between gas and solids.

In order to achieve a retorting process that is economical, continuous, and highly reliable, any equipment usable in the process must permit a high unit through-put of material, since enormous quantities of the oil shale must be handled for a relatively nominal recovery of shale oil. Process equipment for oil shale processing must have a high thermal efficiency which requires little, if any, cooling water. As in the case of oil mechanical devices, the retorting equipment should be as simple as possible so that relatively proven and economically attractive mechanical devices may be utilized in the operation of the retort. In an effort to provide an economical commercial process, literally hundreds of retorting processes have been proposed, each of which offers a somewhat different choice and/or combination of the many possible operating conditions.

Existing retorting processes have been grouped into four classes according to the method of heat transfer to the shale.

Class I - Indirect Heat Transfer Retorts

Heat is transferred to the shale through a wall. The simplest form of this retort is a Fischer assay device for measuring the amount of oil that may be recovered form a sample of shale. The shale is placed in a closed container and heated by means of a fire outside of the retort. The retorted gas and liquids, uncontaminated by air and the sulfur compounds are in a reduced state, such as H_2S. Because the heat source is external to the retort, any fuel can be used. This type of retort is expensive in terms of capital and operating costs per unit of produced oil. It is not likely to be competitive with other types of retorts.

Class II - Combustion Zone Retorts

Heat is transferred to the shale from hot gases generated in the retort by the combustion of some of the carbon and hydrogen present in the shale. Examples are the gas combustion retort, the Union Oil Company retort, and the Laramie simulated in-situ retort. A controlled amount of air and recycle gas is introduced into the retort and a mixture of product oil and low Btu gas is recovered. The advantages of this system are low capital and operating costs per unit of shale input. Disadvantages are low recovery of the total energy in the shale and the production of a large quantity of flue gas containing about 80 Btu/SCF energy content. For example, a typical gas combustion retort plant producing 16,000 m^3 (100,000 barrels) per day of shale oil would also produce about 23 million cubic meters per day of low Btu gas.

Class II retorts produce a large quantity of low heating value (3.7 MJ/m or 100 Btu/SCF) gas as a byproduct, and most of the sulfur in this gas is in the form of SO_2. The residual shale has had most of the organic carbon removed.

Class III - Externally Heated Gas/Liquid Retorts

Heat is transferred to the shale by passing previously heated gases or liquids through the shale bed. Two examples are the Petrosix retort and the Union B retort. By recirculating high Btu product gas through the retort, the problems of the Class II retort are eliminated. The gas has much more value and sulfur compounds can be removed by amine scrubbing. However, the capital cost of the equipment required to heat the recirculating gas makes this a very expensive type of retort. Additional problems are caused by the tendency of the external gas heater to accumulate carbon deposits caused by oil mist in the gas. It is not likely that this class of retort will become commercial.

Class IV - Externally Heated Solid Retorts

Heat is tranferred by the introduction of hot solids into the retorting bed. The two best known examples of this class are the TOSCO II retort, in which heat is transferred by ceramic balls, and the Lurgi-Ruhrgas retort, in which heat is transferred by recirculating hot shale ash. The purpose of retorting is to combine raw shale with enough hot recycle solids to produce retorting temperatures in the mixture. This class of retort is fairly expensive, but does recover a high percent of the energy in the shale. The gas from the retort is a high Btu gas, and sulfur compounds are in their reduced state. Both TOSCO II and Lurgi-Ruhrgas retorts have the potential to become commercial.

In the TOSCO II retort, the ceramic balls are heated in a separate furnace which may be fired with any acceptable fuel. The Lurgi-Ruhrgas retort employs a lift burner to burn the residual carbon from the educted shale so that no additional fuel is required to supply retorting heat. The Lurgi Company claims that very little SO_2 is found in the flue gas from the lift burner because it is absorbed on the fine shale particles.

Class IV retorts produce gaseous products that are not diluted with air so that the gas has a high heating value and the sulfur is in the reduced state. The residual organic carbon may remain on the spent shale (TOSCO II) or it may be burned off in a subsequent process step (Lurgi-Ruhrgas). Generally, the residual shale is in the form of small particles.

The retorting process considered most promising on the basis of ease of environmental effluent control, shale oil extraction efficiency, and technical advancement is the Oil Shale Corporations's TOSCO II retort. This system, involving a horizontal rotary kiln heated by externally fired ceramic balls, has several specific advantages:

- Low, controlled temperature, retorting allowing a minimum of carbonate decomposition.
- Production of undiluted, high Btu retort gas - possible because the heat required for retorting is generated (by combustion) external to the retort.

- o Extremely high shale oil extraction - posssible because of the system's capability to utilize finely crushed shale.
- o The production of an additional fuel source in the form of carbonaceous residue remaining on the spent shale.
- o Many years of active investigation, optimization, and refinement of the retorting process culminating in the successful, continuous operation of the largest capacity oil shale retort in the United States.

A possible variation in the use of TOSCO retorts showing promise would be the combined use of both TOSCO retorts and some vertical shaft retort, e.g., Gas Combustion, Union Oil, or Petrosix retorts. Such a combination would allow an improved efficiency in the crushing and screening variations. This is done by using the larger pieces of shale for the vertical shaft retorts and the fines for TOSCO retort, thus reducing both the quantity of fines generated and the required degree of crushing. In addition to the economic advantages (from reduced equipment requirements and energy and water usage) the possibility of air and land pollution would be lowered. Another possible advantage from a combined operation would be the use of low Btu retort gas from an internal combustion heated vertical retort (Gas Combustion or Union Oil retorts) to provide fuel to heat the ceramic balls for the TOSCO retort, which, because of its high sulfur concentration, can be economically desulfurized and used as a high quality, clean burning on-site fuel gas or exported.

Thermal Efficiency

The tranfer of heat to the shale by externally heated materials is normally a far less efficient process than direct heat transfer by internal combustion. However, because of several offsetting advantages resulting from this retorting method, better overall shale oil extraction is accomplished. The exclusion of combustion products, mainly nitrogen, allows the production of an undiluted retort gas. In addition, the heat required to raise the temperature of the incoming combustion air is conserved. Another advantage of this mode of retort heating is the minimal decomposition of inorganic carbonates in the shale resulting from greater shale agitation and hence controlled temperature retorting. Limiting thermal decomposition reactions results in additional heat savings.

URANIUM ENRICHMENT

In the United States, uranium ore is mined and milled into yellow cake, which is refined and converted into highly purified uranium hexafluoride suitable for isotropic enrichment by gaseous diffusion plants.

The enriched uranium 235 is used primarily to manufacture fuel pellets which are then clad with metal for use as reactor fuel rods in power plants, as well as nuclear powered ships and submarines. Reprocessed uranium from replaced fuel rods can also be converted to uranium hexafluoride and reenriched.

In the enrichment process, gaseous uranium hexafluoride is diffused though a series of porous membranes that are arranged in cells in a cascade pattern. Since the uranium 235 diffuses at a slightly faster rate than the uranium 238, a large number of stages are required. Huge amounts of electricity are required to run the compressors, and corresponding great quantities of cooling water are required to cool them.

There are three gaseous diffusion uranium enrichment plants. Union Carbide Corporation runs the Paducah, Kentucky and Oak Ridge, Tennessee plants, and Goodyear Atomic runs the Portsmouth, Ohio plant. The Paducah plant enriches uranium to over one percent uranium 235; the Oak Ridge Plant is up to four percent uranium 235; and the Portsmouth Plant enriches uranium up to as high as 97 percent uranium 235.

By far, the most significant rejected heat stream in gaseous diffusion is non-contact cooling water. This water cools an intermediate heat transfer fluid, which in turn provides interstage cooling for the compressed uranium hexafluoride.

In 1977, the Paducah plant used about 91,500 gallons per minute of cooling water. Inlet temperature to the process building was about 97°F and the outlet temperature was about 155°F for a total heat load of about 22.8×10^{12} Btu per year.

The Oak Ridge plant used about 250,000 gallons per minute of cooling water. The cooling water was heated from 95°F to 155°F, amounting to 53.8×10^{12}Btu per year of rejected heat.

The Portsmouth plant used around 312,000 gallons per minute which was heated from 70°F to 140°F. This represents 94.2×10^{12}Btu per year of rejected heat.

The total waste heat rejected by these three plants amounts to 1.71×10^{14}Btu per year (0.171 quads).

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SECTION 9

WASTE HEAT RECOVERY TECHNOLOGY

INTRODUCTION

Waste heat recovery involves the transfer of heat energy from a fluid waste stream, product or byproduct, to a process stream in such a manner that net heat energy transfer results in a credit to the overall energy balance of the process. Some devices which can accomplish this transfer of heat energy are called heat exchangers, heat engines, or heat pumps.

This section of this report compares various heat transfer techniques either presently employed or actively being researched by industry for the recovery of waste heat.

TYPES OF HEAT EXCHANGERS

There are three broad categories of heat exchangers according to the mode of heat tranfer:

- Open heaters mix the hot and cold fluids directly.
- Heat is directly transferred from one fluid to the other through a separating wall. This requires the simultaneous flow of the two fluids.
- Heat is intermittently stored after extraction from a hot fluid and used to heat the cooler fluid. The hot and cold fluids must alternate on a more or less regular basis in their flow through the heat exchanger.

The first type has very limited usefulness in waste heat recovery. Examples of the second type are recuperators, boilers, condensers and evaporators. Type 3 heat exchangers are usually called regenerators. Examples are the bricktype regenerators of openhearth and glass furnaces, and wheel type air preheaters (heat wheels). Currently, recuperators are much more common in industrial waste heat recovery than are regenerators.

Heat exchangers are further classified with respect to the phase of fluids involved in heat transfer. These can be gas to gas, liquid to gas, or liquid to liquid. Further, the device may be single pass or multipass according to the number of times the heating or cooling media passes over the heat transfer surface. There are three basic arrangements of heating and cooling fluid flow streams:

- Parallel Flow - Both fluids flow in approximately the same direction.
- Counter Flow - The fluids flow in opposite directions.
- Cross Flow - The fluids flow at right angles to each other.

The choice of an appropriate heat exchanger for waste heat recovery will be strongly influenced by economic and environmental factors. Selection of a heat exchanger must include four main steps:

- Quantify and qualify the waste heat rejected by a process.
- Identify prospective uses for the waste heat.
- Review presently available waste heat technologies according to the temperature range of the waste heat.
- Make an economic analysis of each of the options.

For step one in the selection decision some essential parameters of the fluids involved must be considered to make an optimum choice of a waste recovery device.

Waste Heat Fluid	Heated Fluid
o Temperature	o Temperature
o Flow Rate	o Control Temperature (if desired)
o Chemical Composition	o Chemical Composition
o Minimum Allowable Temperature	o Maximum Allowable Temperature

This section examines waste heat recovery technologies presently employed by industry. There will be a process description, giving temperature of the waste heat stream that is most effectively recovered by such a device, applications in industry, and limitations and/or specific advantages for each technique.

The following is a list of heat recovery techniques either presently employed or actively being researched by industry that were considered for this report:

- Recuperators
- Regenerators
- Heat Pipe Exchangers
- Economizers (Finned Tubes)
- Shell and Tube Heat Exchangers
- Waste Heat Boilers
- Gas and Vapor Expanders
- Heat Engines (ORC)
- Heat Pumps

These techniques will be examined and grouped by the temperature range of waste heat streams for which they are best suited for economical waste heat recovery. Temperature ranges considered are medium temperature (250°F to 1200°F) and high temperature (1200°F to 2000°F). The low temperature range (less than 250°F) did not prove advantageous for heat exchanger devices but systems such as heat pumps and organic rankine cycles do operate in this range.

High Temperature Range (1200°F to 2000°F)

Radiation Recuperator

This device consists of two concentric lengths of metal tubing. The inner tube carries hot flue gases while the external sleeve carries cool intake air. The cool air from the atmosphere is heated by the exhaust gases and sent to the combustion chamber. Gas flows in the metallic radiation recuperator are usually parallel, though more efficient heat transfer can be accomplished by using counter flow design. However, parallel flow is generally used because it serves the additional purpose of cooling the exhaust gas duct, thereby extending its life. At temperatures greater than 2000°F parallel flow must be used in order to maintain sufficient cooling of the inner gas duct. More elaborate designs of radiation recuperators incorporate two sections; the bottom operates as parallel flow while the upper section uses the more efficient counterflow arrangement.

Limitations

The principal limitation of heat transfer by the metallic radiation recuperator is the reduced life of the stack liner at temperatures exceeding 2000°F. Thus, it was necessary to use the less efficient parallel flow method at these temperatures. In addition, when furnace combustion air flow is cut back as a result of reduced load, excessive heat transfer rates occur between hot waste gases and preheat combustion air, causing rapid surface deterioration. This makes it necessary to provide an ambient air bypass to cool exhaust gases to an acceptable level.

Applications

Recuperators find extensive use in industrial waste heat recovery. Typical applications are in soaking ovens, annealing ovens, melting furnaces, gas incinerators and radiant tube burners. Radiation recuperators are strictly used in high temperature applications.

Like radiation-type recuperators, the convection-types are used extensively in industrial waste heat recovery. However, convection types find use in the medium to high temperature range.

Convection Recuperator

This is another form of recuperator where the hot exhaust gases are carried through a series of parallel, small diameter, metal tubes, while process air to be heated enters a surrounding shell and passes over the tubes to one or more times in a direction normal to the pipe axis. Baffles are used to allow the air to pass over the tubes more than once. Baffling increases both the cost of the recuperator and the pressure drip in the combustion air path. However, the effectiveness of heat exchange is increased. Convection recuperators have a higher effectiveness than radiation recuperators because of the larger heat transfer area offered in multitubing and multipass baffling.

Ceramic tube recuperators have been developed that allow operation on the gas side to 2800°F and on the preheated air side to 2200°F on an experimental basis and to 1500°F on a practical basis.

Limitations

Metal tube recuperators exhibit the same temperature limitations as radiation types. As mentioned previously, ceramic tubes were developed to overcome this. A big problem of earlier cermamic type type recuperators was maintenance of seals in the air headers and deterioration of tubes because of thermal cycling. Silicon carbide tubes, joined by flexible seals in the air headers, have reduced leakage rates to a few percent and increased tube life. Previous leakage rates were from 8% to 60%.

Replacement of individual tubes upon failure poses a problem in conventional tube recuperators. Furnace shutdown is required to remove the header box to replace tubes. An alternative arrangement of the convective recuperator is one where the cool combustion air is heated in a bank of parallel vertical tubes which extend into the waste gas stream. Replacement of faulty tubes can be done during full furnace operation.

Ceramic Heat Wheels

Heat wheels, or rotary regenerators, are a heat transfer device in which a laminar wheel slowly rotates between two adjacent ducts; one a cold gas duct and the other a hot gas duct. As the disc slowly rotates it absorbs sensible heat (and in some cases, moisture containing latent heat) from the hot gas duct and delivers it to the cold gas duct. Ceramic heat wheels form a matrix of heat wheels used for high temperature waste gases. Treatment of the matrix with a hygroscopic material, one which readily absorbs water such as Lithium Chloride, will allow the latent heat of water vapor to be recovered from flue streams. This represents a considerable increase in energy recovery since water vapor is a combustion product of all hydrocarbon fuels. Efficiency of vapor recovery in some units reaches 50%. Overall efficiency of sensible heat transfer for wheels generally runs up to 85%.

Limitations

If a heat wheel is used to heat process air and if inlet air temperatures must be held constant, then a variable speed drive will be necessary. In applications in subzero temperature, high humidity areas, there will be a need to install an air preheat system to prevent frost formation. Where gases with large amounts of process dust or adhesive contaminants are handled, air filters will be needed.

Cross contamination between intake and exhaust ducts is a problem associated with heat wheels. The addition of a purge section on the wheel, where clean air is blown through the wheel and exhausted to the atmosphere at regular intervals, will limit gas contamination to under 0.1%.

The temperature limitation of the heat wheel is mainly because of mechanical difficulties caused by uneven heating of the wheel. This results in uneven expansion, causing deformations of the wheel, and thus difficulty in maintaining adequate air seals between duct and wheel.

Generally, heat wheels cannot compete economically with recuperators for small furnace applications because the motor, instrumentation and electrical equipment of the heat wheel are more or less independent of size. Thus, capital investment for heat wheels is much too large for small furnace applications and cannot be justified. Heat wheels for the flue gas volume rates between 40,000 - 60,000 SCFM are not uncommon (flue gas rates of 5,000 - 10,000 SCFM represent the lower operating ranges). Operating temperatures can range up to 1200°F to 1400°F, though one manufacturer has indicated that research on air to air heat wheels up to 4000°F might well be done if the market existed.

Applications

Typical applications of heat wheels are in roof top energy recovery systems to supply space heating. Other uses would be process heat recovery for combustion air, drying air, and other processes where hot air is necessary.

Refractory Regenerators

Regenerators operate on the principle of storage and release of sensible heat. The storage medium is a solid material, fireclay, chrome or silica brick, which absorbs heat from and releases heat to alternating flows of hot and cold gas. A "checkerwork" design allows easy passage of gas through the brick structure which is generally housed in a steel shell. More complicated designs have been introduced with more complicated heat absorbing elements. However, the high cost of refractory regenerators has tended to keep these devices in a more or less standard design. The regenerators are often used in conjunction with blast furnaces, open hearth furnaces, coke ovens, and glass furnaces, to preheat air for these processes. Initial preheats from a typical regenerator of this type are very high for the first few minutes of its "on wind" cycle but gas temperatures drop very rapidly. A typical blast furnace stove (one from a regenerator) produces preheated air initially at 2000°F. However, the temperature drops to 1000°F one hour later, after removal of less than 5% of the total available heat in the stove.

Limitations

Checkerwork regenerators suffer from design deficiencies such as high initial cost, low thermal efficiency of the refractory material, loss of efficiency as the surface fouls, and inaccessibility of the heat transfer surface. A regenerator that does not suffer these deficiencies is the "pebble bed" type regenerator, which uses small refractory particles enclosed in a bricklined steel shell. Air preheats as high as 3600°F have been obtained in this type of regenerator.

Applications

Checkerwork regenerators are used in the steel, iron and glass industries for the recovery of heat from furnace flue gases.

Medium Temperature Range (250°F to 1200°F)

Metallic Heat Wheel

The process description is the same as that for the ceramic heat wheel. The metallic heat wheel finds application in low to medium temperature ranges as a result of mechanical difficulties related to uneven wheel expansion at high temperatures.

There are two types of metallic heat wheels. The first consists of a knitted mesh stainless steel or aluminum wire core packed in a metal frame. The second is a laminar wheel, fabricated from corrugated metal, and is composed of many parallel flow passages. A typical installation has a heat wheel installed between adjacent hot and cool gas ducts. The heat wheel is supplied with exhaust fans, prefilters for each duct, and a wheel motor drive. Variable speed drives are available to maintain constant air temperature.

Limitations

The limitations of metallic heat wheels are basically the same as detailed in the description of the ceramic heat wheel.

Applications

Comfort heating or cooling is the primary use of metallic heat wheels. In the summer season the heat wheel can be used to cool the incoming air from the cooler exhaust air. This can reduce the air-conditioning load by as much as 50%. Other typical uses of heat wheels for low to medium waste gas temperatures are process heat recovery for curing or drying ovens and air preheaters, in all sizes, for industrial and utility boilers. They are also used for space heating and cooling where large quantities of ventilation air are needed for health or safety reasons.

Passive Gas to Gas Regenerator (Air Preheater)

Air preheaters are constructed of alternate channels of a conductive metal which puts the flows of the heating and heated gas in close contact with each other, separated only by a thin wall. It is a crossflow gas to gas heat exchanger that performs many of the functions of a heat wheel. It is used in place of a heat wheel where no cross contamination can be tolerated. It has the additional advantage of mechanical simplicity because the air preheater does not need a drive mechanism.

Limitations

With a passive regenerator there is the advantage of simplicity of design. However, this advantage can be lost if there is a need to have temperature control. These devices also occupy more volume and are more expensive than heat wheels since much greater transfer surface area is required.

Applications

Passive regenerators are used in industry to recover heat from exhaust gases to heat other gases in the low to medium temperature range. Uses are in heat recovery from steam boiler exhausts, baking, drying and curing ovens, gas turbine exhausts, gas and vapor incinerator exhausts, and reduction of building air conditioning loads.

Heat Pipe Exchange

The heat pipe is a counterflow to gas heat exchanger where the elements of the exchanger form a bundle of pipes extending from the inlet to the exhaust duct. A partition separates the ducts to eliminate cross contamination. The pattern resembles a finned tube heat exchanger. Each pipe is a separate sealed element consisting of an annular wick extending over the inside length of the tube in which an appropriate heat transfer fluid is entrained. Thermal energy applied to either end of the pipe causes the refrigerant at that end to vaporize. The vapor travels to the cold end carrying latent heat of vaporization. Thermal energy is removed causing the vapor to condense to liquid. The liquid is carried by capillary (and/or gravity) action back to the hot end, thus completing the cycle. Absence of cross contamination and compact size, along with the inherently efficient heat transfer properties of the finned tube bundle, are the main advantages of this system. Though this heat transfer element has only recently become commercially available, its high efficiency makes it an attractive industrial heat recovery operation for low and medium temperature waste heat.

Limitations

Allowable temperatures and temperature differentials are limited by the phase equilibrium properties of the internal fluid.

Applications

Applications of the heat pipe are in air preheaters for steam boilers, air dryers, brick kilns, drying, curing and baking ovens, waste steam reclamation, and heating, ventilating and air conditioning systems.

Finned Tube Heat Exchangers (Economizers)

Economizers are gas to liquid heat exchangers generally used in the production of hot water from waste gases in the low to medium temperature range. The heat exchanger consists of a bundle of tubes, which hold the liquid to be heated. Fins are radially or helically wound around the tubing by wrapping or extruding the fins which are attached, by tension of the fin, mechanical bonding, welding, brazing, or soldering. The fins may be smooth, ruffled at the base, or serrated, and the spacing and size is dictated by the type of fuel from which the waste gas is produced. Tubes are connected in series or can be connected in parallel-series to control the liquid side pressure drop. Air side pressure drop is controlled by the spacing of the tubes and the number of rows of tubes within the duct. Economizer casings are generally made of carbon steel for operations to 600°F, or aluminized or stainless steel for higher temperatures. Special construction is available for use with corrosive liquids and/or gases.

Limitations

Selection of a finned tube heat exchanger for process heat recovery depends on evaluating cost and reliability of the bond between fin and tube, temperature and material limitations, corrosion (especially for bimetal products), fouling and cleaning, as well as the usual heat transfer efficiency. If heavy oil is used as a fuel, it is necessary to shut down occasionally to blow accumulated particulate matter off the fins in the unit. Such an accumulation will cause a drop in draft pressure and a reduction in heat transfer efficiency.

Applications

Finned tube heat exchangers are used to recover waste heat in a low to medium temperature range, from hot exhaust gases, for heating liquids. Some uses are in domestic hot water heating, heating boiler feed water, hot water space heating, absorption type refrigeration or air conditioning, and heating process liquids.

Shell and Tube Heat Exchangers

Shell and tube heat exchangers are gas or liquid to liquid heat recovery devices. When the medium containing waste heat is a liquid or vapor which heats another, this type is used since both paths must be sealed to contain the pressures of their respective fluids. The device consists of a metal shell containing a tube bundle and internal baffles, which serve to direct the shell fluid in multiple passes over the tubes. The baffles also act as tube supports. Since the shell is inherently weaker than the tubes, the higher pressure fluid circulates in the tubes, while the low pressure fluid circulates in the shell. When a vapor contains the waste heat, it generally is contained in the shell since, if it were in the small diameter parallel tubes, any condensation would cause flow instabilities.

Classification of shell and tube exchangers is by the arrangement required to reduce the thermal stresses between the tubes and shell. The four main types presently used are fixed tube sheets, internal floating heads, U-tube bundles and outside packed exchangers. These types are described furthe, including their inherent limiations and applications, in the following subsections.

Fixed Tube Exchangers

This is the simplest and cheapest shell and tube exchanger to fabricate. It has fixed tube sheets at each end with the tubes welded or expanded into sheets. Only small temperature differentials between hot and cold fluids are allowed because of mechanical difficulties incurred by high thermal stresses.

Internal Floating Head Heat Exchangers

This design eliminates tubeshell stress using one bolted tube sheet and one floating head cover to which the other tube sheet is bolted. This permits tube motion relative to the shell. The floating tube sheet is clamped between the floating head and a flange so that it is possible to remove the tube bundle for cleaning. External leakage is also greatly reduced.

The principle disadvantage in this system is the internal hidden gasket on the floating end which may fail and cause trouble, depending on the toxicity or reactivity of the fluids.

U-Tube Bundle Exchanger

This design is similar to the fixed tube exchanger. The main difference being that only one shell joint is required, because the tubes make a U-shape bend at the opposite end. Shell-tube stress is eliminated and the design is simpler than other shell and tubes.

As with the fixed tube sheet design, the price paid for simplicity is that a U-tube is difficult to replace and, although the U-tube is removable, it presents problems in cleaning.

Outside Packed Heat Exchanger

This design is similar to the internal floating head type, except that the floating head is external and head gaskets are accessible. The packing gland, which seals in the shell fluid, can be designed for pressures up to 600 psi, but there is the possibility of shell fluid leakage at high pressures.

Because of possible shell fluid leakage, which would be rejected to the surroundings, packed heat exchangers are not recommended when the shell fluid is toxic, expensive, corrosive or flammable.

Exchanger Selection and Operation

The choice of an appropriate shell and tube exchanger will depend largely on the shell side fluid to be used. A compromise based on the following factors is required:

- o Cleanability - Shell cleaning is difficult. Therefore, the cleaner fluid should be on the shell side.

- o Corrosion - Excessive corrosion may dictate the need for expensive

- alloys. Therefore, corrosive fluids are generally placed in the tubes to save the cost of an expensive alloy shell.

- Pressure - Shells holding high pressure fluids must be thick walled, thus, they are expensive to fabricate. Therefore, high pressure fluids are placed in the tubes.

- Temperatures - High temperatures reduce allowable stresses in materials and are a factor in determining shell thickness. Safety of personnel may require extra insulation should high temperature fluids be placed in shells. Therefore, high temperature fluids are placed in the tubes.

- Hazardous or expensive fluids - The tightest side of the exchanger should contain the most hazardous or expensive fluid. In most exchangers, this is the tube side.

- Quantity - By placing the smaller quantity of fluid in the shell, a better overall design may be accomplished.

- Viscosity - The critical Reynolds number for turbulent flow in the shell is about 200. Thus, if the flow is laminar, it may be turbulent if placed in the shell. However, if the flow is still laminar when in the shell, then it is best to place the fluid back inside the tubes, as it will be easier to predict heat transfer and flow distribution.

- Pressure Drop - If pressure drop must be accurately predicted, the fluid should be placed in the tube. Tubeside pressure drops can be calculated with far less error than shell side drops, which deviate widely from theoretical values as a result of shell leakage.

Typical uses of shell and tube heat exchangers are in heating process liquids or space heating by recovering waste heat from liquids or gases. Waste heat media that are frequently used by industry are condensates from refrigeration or air conditioning systems, coolants from furnace doors, grates and pipe supports, coolants from engines, air compressors, bearings and lubricants, and condensates from distillation processes as typical in petroleum refining.

Waste Heat Boilers

Waste heat boilers are used for waste heat recovery in the medium to high waste gas temperature range (generally 400°F to 2000°F). They are used only where there is a need for process steam or hot water. The iron, steel, coke, copper, zinc, glass and ceramic industries have used waste heat boilers since the early 1920's. Process gas temperatures must be high (1000°F to 1500°F minimum) before steam generation is practical. Otherwise, hot water can be generated.

Waste heat boilers can be classified by the arrangement of gas and liquid passes: fire tube or water tube.

Fire tube boilers are designed for the hot gases to pass thorough the boiler tubes which are immersed in the cooling liquid. Water is vaporized and collects in a steam drum to be drawn off. These boilers are compact in size and are used for energy extraction from small waste gas volumes. Gas (tube) side cleaning is fairly easy, accomplished by air or steam blowing with shot cleaning systems used for difficult installation. Shot cleaning systems eject steel shot through, or let the shot cascade over heat exchanger surfaces to remove buildup. A typical fire tube boiler can handle exhaust volumes up to 50,000 SCFM with boiler operating pressures of between 15 to 250 psi (750 psi with special designs). Operating temperatures from 400°F to 3000°F are possible.

Water tube boilers have an arrangement where the hot gases pass over tubes filled with the working fluid. They are generally very large in order to accomodate large waste gas volumes. Unit size can be reduced by utilizing finned boiler tubes to increase effective gas side heat transfer area, though this will increase gas side fouling. Water tube boilers are capable of operating at high steam pressures and can handle exhaust gas volumes up to 1,000,000 SCFM. The pressure and rate of generated steam is a function of the hot gas temperature and flow rate and the efficiency of the boiler. Mud drums and dust hoppers are used to collect any sludge or process dust in the boiler system.

Steam is generated in water tube boilers that are usually of the vertical, natural circulation, or horizontal forced circulation type, the choice being dictated by plant layout. For natural circulation the drum should be some distance above the boiler to give sufficient driving force to the water and steam. However, the cost of additional structure may be higher than the cost of installation of circulating pumps. Some water tube boilers do not require steam drums if they are "once through", that is, the water is converted to super heated steam in the tube itself.

If design and construction are carried out to high standards, horizontal, natural circulation fire tube boilers are more reliable than forced circulation water tube boilers. This is because the latter are prone to failure if dirt or debris gets into the system, especially with vertical boilers that have their low point at the spot of highest temperature and heat flux. However, as faulty water treatment can lead to failure in both types of boilers, the replacement of water tube bundles is easier than fitting a new fire tube bundle. Since many boiler failures are a result of faulty water treatment, it has become common practice to monitor continuously the conductivity of feedwater and to check acid/alkali content.

Limitations

Fire tube boilers suffer the disadvantages of low steam working pressure, difficulty in cleaning the water side of the boiler tubes, and large gas side pressure drops.

Failure to carry out sufficient blowdown procedures can lead to problems. Boiler solids can build up behind the insulating concrete tube sheets which can result in tube failure from overheating.

Water tube boilers experience high water side pressure drops. Other disadvantages are large unit size, difficult water side boiler tube cleaning, and probable need to install refractory protection for shell segments because of high temperature exhaust gases.

Applications

Waste heat boilers are suitable means of waste heat recovery where there is a need for process steam or hot water. Applications of these boilers are generally in the medium (250°F to 1200°F) to high (1200°F to 2500°F) waste gas temperature range. Typical types of waste exhaust employed are from gas turbines, reciprocating engines, incinerators and furnaces. Some firms, required to dispose of fumes from process wastes, find it economical to install waste heat boilers to produce steam from incinerators' waste heat. Waste heat boilers are frequently used as part of a stack or flue gas cleaning operation, effectively cooling the gas for an electrostatic precipitator to remove particulates efficiently.

Gas and Vapor Expanders

Industrial steam and gas turbines are in an advanced state of development and are readily available on a commercial basis. Turbines offer a means of recovering waste heat and converting it to mechanical work or electricity. The steam exhausted by a steam turbine, after removal of the necessary energy to do work or produce electricity, can be used for process heat, by the use of various methods previously detailed. Steam turbines are classified as back pressure turbines (allowable exit pressures about 400 psi) or condensing turbines which operate below atmospheric exit pressures. The steam used to drive the turbine can be generated by a waste heat boiler as part of an intensive waste heat recovery program.

The last two decades have seen a remarkable growth in the application of the industrial gas turbine. Well established design features of steam turbines coupled with the advanced technology of aircraft jet engines has brought the gas turbine to the current state of the art. The advancement of the industrial gas turbine is a direct result of increased turbine inlet temperatures. Thermal efficiencies have increased from 20% to 33% in the past 20 years and allowable inlet temperatures have increased from 1600°F to approximately 2000°F. This improvement is due to technological advancements that have resulted in materials with increased temperature capabilities and also improved turbine cooling techniques.

Significant cycle efficiency improvements will result as ceramic and composite elements replace air cooled metal blades and vanes. Two possible replacement materials are silicon nitride and silicon carbine ceramics. These are high density materials that exhibit superior strength at high temperatures and require less cooling air.

Limitations

A feature of the ideal gas turbine (Brayton) Cycle is the large amount of compressor work compared to turbine work (40% : 80%). When considering the actual cyle, irreversibilities can require a larger amount of compression work compared to turbine work. Thus, the net work (the difference between the two) decreases very rapidly as compressor and turbine efficiencies decrease, thereby reducing the overall efficiency of the cycle. If efficiencies of the turbine and compressor drop below 60%, all the work of the turbine will be required to drive the compressor, and the work delivered will be zero. To achieve maximum turbine efficiencies, inlet hot gas temperatures must be as high as possible without exceeding the working temperature of the construction materials. Due to this, temperature limitations and relatively low overall efficiencies waste gas volumes must be large in order to justify equipment costs. Applications for gas turbine cycles seem to be limited to industries with large waste gas volume flows on the order of 50,000 SCFM.

Applications

Gas turbine cycles are used with various recuperators or waste heat boilers for waste heat recovery from furnace and flue gases for electrical power generation, compressor drives, pump drives or fan drives. Recuperatured gas turbine cycles are frequently used with various bottoming turbine cycles. The bottoming cycle utilizes turbine waste gas to heat the feed liquid turbine cycle such as an organic Rankine cycle or sulfur dioxide cycle.

Organic Rankine Cycle Heat Engine

The Organic Rankine Cycle (ORC) heat engine utilizes low level waste heat and operates on the thermodynamic Rankine cycle. Four processes characterize this cycle:

o Reversible adiabatic compression in the pump.

o Constant pressure transfer of heat in the boiler.

o Reversible adiabatic expansion in the turbine.

o Constant pressure transfer of heat in the condenser.

The working fluid may be superheated before entering the turbine. This heat is added from exhaust vapors which vaporize the fluid. Heat energy is given up by expansion in the turbine to perform shaft work or generate electricity.

The low pressure vapor that exits can now pass through a regenerator where it preheats the boiler feed. The vapor passes to the condenser where it gives up its latent heat of vaporization, which may be used by another heat recovery process for low temperature requirements, such as domestic hot water heating. The pump then brings the fluid up to boiler pressure, after which the fluid passes through the regenerator to be preheated before entering the boiler to complete the cycle. The ORC uses organic compounds as working fluids due to their low specific heats and positive or vertical slope saturated vapor lines on temperature entropy (TS) diagrams. A positive slope saturated vapor line indicates that a fluid becomes superheated upon expansion in the turbine. There is no moisture accumulation and thus less chance of corrosion to the blades. To achieve maximum efficiency with this cycle, a regenerator must be installed to recover the sensible heat in the turbine exhaust to preheat the boiler feed. This increases efficiency, but also increases the complexity of the system. Positive vapor line fluids are called drying fluids. Examples are refrigerants R113 and R114.

Vertical saturated vapor line fluids are called isentropic fluids. Saturated vapor leaving the boiler will emerge from the turbine expansion process as saturated vapor. Thus, maximum effective use is realized from the available temperature difference without the use of additional heat exchanger equipment. This cycle will only differ from the Carnot cycle by the amount of heat needed to raise the temperature of the condensate fluid to boiler temperature. Thus, a low value of specific heat (Cp) for the fluid will allow the cycle to approach maximum thermal efficiency. Two fluids that approach isentropic expansion are refrigerant R11 and Fluorinol 85, which are examples of light organic fluids.

These considerations are independent of design constraints that must be imposed on equipment. Turbine rotor stress must be minimized. Since stress is proportional to the square of the turbine tip speed, which is inversely proportional to the molecular weight of the working fluid, it is apparent that a high molecular weight fluid will minimize stress. High molecular weight fluids also minimize turbine speed. High density fluids minimize the physical size of the turbine and piping. Thus, high molecular weight, high density fluids should result in reasonable equipment design.

Limitations

Many working fluids considered are volatile fluorinated hydrocarbons and as such, any leakage from the system should be minimized for environmental reasons. At continuous operating temperatures of 300°F for the three refrigerants R11, R113 and R114, the maximum decomposition rate is less than 0.5% per year.

An important limitation imposed on a prospective system is the maximum operating temperature of the working fluid. At elevated temperatures and in the presence of such contaminants as oil, water and certain reactive metals, organic fluids can decompose into various halogen (F, Cl, Br) gases and acids. This results in reduced performance of heat exchangers, corrosion due to acids, and reduction of total fluid in the system. Some of the higher temperature working fluids can present an explosive or flammable hazard in the case of a leak. More tests need to be done on the environmental effects from chemical reaction of working fluids and flue gases in the case of leaks.

Application

The ORC system is readily adaptable to a bottoming cycle for reciprocating engines, turbines and other manufacturing processes, as well as furnace gases and geothermal heat sources. The system uses no fuel, as the waste heat fluid is transmitted to the system vaporizer directly, and for this reason has great potential in the field of waste heat recovery.

Low Temperature Range (Subzero to 250°F)

Heat Pumps

A heat pump is a device that extracts heat from a low temperature reservoir (heat source) and delivers it to a higher temperature reservoir (heat sink). By the second law of thermodynamics, this is impossible without an input of work to the system. The heat pump cycle is in effect, the reverse of the engine cycle, which is the basis of the ORC engine. The basic components of the heat pump are the evaporator, condenser, compressor and expansion device. A refrigerant fluid passes through an evaporator where it absorbs heat at a low temperature and is completely vaporized. The low temperature vapor goes to a compressor where external work is added to increase the pressure and temperature of the fluid. The fluid now passes to a condenser where it condenses to give up its heat energy to another fluid that must be heated. The refrigerant fluid must now be expanded through a capillary tube or expansion valve before entering the evaporator to complete the cycle.

The industrial heat pump operates on the same principle as the residential heat pump/air conditioner, only using much larger compressors at higher temperature levels. It was developed as a space or hot water heating system where low temperature free waste heat from industrial processes is used as a heat source. Heat engines are rated on thermal efficiency, which is roughly the ratio of work output to heat input. For a heat pump, the efficiency is expressed as the coefficient of performance (COP), roughly the ratio of heat output (from the condenser) to work input (to the compressor). Industrial heat pumps generally deliver COPs of 2.5 to 3.5. A typical industrial heat pump uses two-stage compression, two expansion valves and a flash collecting tank, which collects the fluid as a liquid-vapor mixture. A portion of the vapor is bled off to the inlet of the second compression stage: evaporator and condenser, or shell and tube type with steel tube sheets and removable copper tubes (finned in the case of the evaporator). Each compressor is a single stage centrifugal unit with aluminum alloy impeller and hermetic separately cooled helical gear driven motor. Stainless steel heat exchanger materials may be needed where corrosion or fluid content considerations dictate.

Limitations

Important limitations to successful use of the heat pump as a waste heat recovery device are the average operating temperatures of the heat source and heat sink. The higher the temperature level of waste heat sources, the greater is the potentially recoverable energy content. However, waste heat temperatures supplied to the heat pump are limited, due to the present day compressor and refrigerant technology. In general, the closer the desired fluid temperature is to the waste heat source temperature, the more efficient is the heat pump. Process steam raising by a heat pump is ineffective because when the temperature difference between heat source and sink is greater than 100°F, an electrically driven heat pump consumes more energy than is required by direct heating of the process fluid.

Application

Industrial heat pumps are used to produce hot water or space heat from various low temperature waste heat sources, a list of which follows:

- Overheat vapors from distillation processes
- Warm water effluent from plant processes
- Refrigeration equipment cooling water
- Electric welder cooling water
- Extruder cooling water
- Injection welder cooling water
- Cooling tower water
- Condenser cooling water from power plants

In the past, the heat pump did not see much use as a waste heat recovery device, but manufacturers are now redeveloping their domestic heat pump systems for industrial applications.

SECTION 10

ENVIRONMENTAL IMPACTS OF WASTE HEAT DISCHARGE TO THE ENVIRONMENT

GENERAL

The environmental impacts which may result from the discharge of waste heat to the environment may be separated into two general categories: 1) those impacts resulting from the assimilation of the various pollutants contained in the waste heat stream, and 2) those impacts resulting from the release to the environment of the heat energy contained in the waste heat stream.

HEAT STREAM POLLUTANT IMPACTS

This report presents no detailed dissertation on the pollutants contained within the waste heat stream, since their occurrence and effects are generally site specific. The impacts resulting from the assimilation of the various pollutants contained in the waste heat streams are related to the pollutants' chemical nature, the concentration relative to the recipient environment's ambient conditions, the land use of the affected area, and other factors. Due to the quantity of technical data already existing concerning the behavior and impacts of these pollutants, a further review of this subject is not warranted herein. However, it must be noted that any action which results in an increase in the efficiency of energy utilization, whether it be via waste heat recovery or general conservation practices, may be considered as a pollution control alternative in that these actions will reduce fuel consumption with a corrsponding reduction in the quantity of pollutants discharged.

DIRECT THERMAL IMPACTS

Heat is unlike most "pollutants" which can be readily collected, concentrated, and disposed of under controlled conditions. Heat energy must be disposed of through retention with controlled dissipation, so as to minimize its effects on the surrounding biosphere.

Waste heat discharged to the environment by industry can create undesirable thermal loading of the local environment. The impact of these heat additions is dependent upon both the concentration and route by which this heat energy is discharged.

AQUEOUS ABSORPTION

Heat rejection by cooling and process waters can be a significant amount of the overall waste heat discharged in some industries. Until recently, a common method of waste heat disposal was to discharge once-through cooling water into a nearby waterway. This has proven to be both efficient and economical. However, concern over the potential adverse environmental impacts caused by the addition of this waste heat to natural waterways has promoted considerable research in an attempt to define these impacts, in order to determine "acceptable" levels of thermal pollution. It can generally be stated that the larger the receiving body of water, the less degradation will occcur as a result of increased thermal loading. However, extremely sensitive areas such as estuaries deserve complex investigations.

Temperature is one of the most important single factors governing the occurrence and behavior of life. The discharge of waste heat into a natural body of water can cause a number of physical, biological and chemical changes. Raising the temperature of water reduces the oxygen retaining capacity of the water, reduces the reaeration rate, changes the density which may in turn result in stratification, increases the rate of evaporation, increases the rate of many biological, chemical and physical reactions, and decreases the viscosity, thereby reducing the sediment transporting ability of the water.

The impacts of these changes may vary significantly, depending upon the extent of these changes and the intended use of the receiving body of water. Heat inputs into a receiving body of water increase the rate of BOD exertion which, when coupled with the accompanying reduced reaeration rate, may reduce its organic waste assimilation capacity. On the other hand, the addition of waste heat during winter months may significantly lengthen the shipping season of a waterway by shortening the period of ice cover in the shipping lanes.

The greatest potential impact of waste heat discharges to natural bodies of water is upon the aquatic ecosystem. Temperature increases in a natural waterway will affect the chemical equilibrium by decreasing gas solubilities, thereby allowing oxygen to escape, and by increasing salt solubilities. Substantial temperature increases will alter species' diversity; their metabolic rates, reproductive cycles, and behavioral patterns may also change. Eutrophication and greater parasitic bacterial populations may also follow heat additions. Each of these factors has the potential to create an unbalanced, unchecked aquatic ecosystem. Although a large number of studies have been and are being conducted in attempts to further define these cause and effect relationships, considerable data is still lacking.

ATMOSPHERIC ABSORPTION

Although the potential adverse environmental impacts of discharging waste heat into the aquatic environments are quite numerous and diversified, the direct release of this waste heat to the atmosphere is not without its own potential for adverse environmental impact.

It is becoming increasingly apparent that man affects the climatic conditions of the earth by the release of heat and chemicals to the atmosphere. For this reason, stack gases and cooling tower plumes are of considerable concern to investigators from an environmental and energy standpoint.

Several studies have suggested that the possible intensification of convective activity and the associated concentration of vorticity may be caused by the release of large quantities of heat in relatively small areas, resulting in severe thunderstorms and tornadoes. On a smaller scale, the release of this heat, and the moisture contained therein, can increase or change the spacial and temporal pattern of precipitation, cloud cover, and mean temperatures.

Cooling towers, either wet-or-dry, are frequently used to dissipate waste heat to the atmosphere. The major complaint from the public concerning these towers has been the appearance of these devices and, at close range, the noise generated by them. There are, however, several environmental impacts directly related to the operations of these towers. Some of these are: 1) the restriction of sunlight caused by visible plumes ("shadowing"), 2) restriction of visibility when plumes reach ground level (fogging), 3) deposition of detrimental chemicals contained in cooling waters onto surrounding areas ("drift"), and 4) atmospheric changes. For most sites these impacts are rather small and local, and usually environmentally acceptable.

Proven mathematical models are not yet available for accurately predicting the extent and frequency of these atmospheric effects for a particular site and heat-dissipation system. Consequently, considerable field research will be required to develop these models before accurate determinations of "critical heat loads" may be projected.

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APPENDIX A

USE OF NATIONAL EMISSIONS DATA SYSTEM (NEDS) LISTING FOR DETERMINATION OF WASTE HEAT DISCHARGES

Introduction

The major source of data on flue gases was the National Emissions Data Point Source Listings. This system is part of a program established by the United States EPA to collect and compile data necessary to provide a data base necessary for the National Air Data Branch (NADB) to meet its responsibilities of preparing and distributing periodic reports on air quality and air pollutant emissions. Although this system provides a variety of different reports, only the Point Source Listings were utilized for this report. Further information concerning the appropriate sources of additional data may be obtained from:

Chief, Request and Information Section
National Air Data Branch
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Environmental Protection Agency
Research Triangle Park, North Carolina 27711

General Description - 'Point Source Report'

Sources emitting more than a specific amount per year of any one of the five criteria pollutants (particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide) are classified by EPA as point sources. The basic "Point Source Report" produces a full, formatted listing of all relevant identifying and descriptive point source data as well as estimated and NEDS calculated emissions for each criteria pollutant. More specifically, the following information is available for each emission point for each criteria pollutant:

a. Geographic Location
b. Year of Record
c. Modeling Parameters - UTM coordinates, stack height, diameter, temperature, etc.
d. Emission data - Throughput rate, estimated emissions, estimation method, control equipment, control efficiency, etc.
e. Allowable Emissions
f. Compliance Status
g. Operating Information
h. Annual Fuel Consumption
i. Source Operating Characteristics

Specific data required for the calculation of the waste heat energy content of the flue gases was taken from the data submitted on the "Point Source Listings". Difficulty was experienced in attempting to access the data on the NEDS computer tapes due to the use of a non-standard tape format. This problem was ultimately solved and pertinent data was transferred to another tape for subsequent data reduction and compilation.

After review of the data contained on the computer tapes, comparisons were made between the data reported and other sources of similar data. This indicated several minor problems with the data reported on the "Point Source Listings".

The first problem centered on attempting to identify the point source of the discharge within a specific Standard Industries Classification (SIC). The NEDS Implementation Planning Program Process (IPP) codes were established for each SIC.* However, many of the IPP codes were incomplete, thus not providing any appropriate IPP code for some processes. One such example is the IPP codes for Chlor-Alkali (SIC 2812). The AEROS manual only provides two codes; XX which is for combustion boilers for power, and 01 for conveying, transfering and loading of soda ash. Consequently, many respondents of the Point Source Listings either selected their own IPP number or left the IPP code blank. For the purpose of this report, blank IPP codes are indicated by BL.

Another problem was encountered with the magnitude of the quantities and temperatures reported on the Point Source Listings. The instructions for completing the Point Source Listings require right justification of all numerical entries with decimal points fixed on the imput cards. Some of the values reported from the data bank were several orders of magnitude larger than could be justified for the reported process. In addition, some flue gas discharge temperatures were in excess of 5000°F, obviously indicating erroneous entries on the input cards. All output data from the NEDS computer tapes were closely reviewed and any inconsistent values were either deleted or, in most cases, corrected to values considered representative of the type of discharge.

Although not a problem with NEDS data, there is one improvement to the Point Source Listings which would greatly improve the applicability of the NEDS data to waste heat recovery potential. This would involve the reporting of the duration and/or frequency of the flue gas discharges. Obviously, devices designed to recover waste heat from continuous discharges would not be applicable for use on intermittent discharges of waste heat. Existing data on the Point Source Listings do account for the number of hours per day, days per week, and weeks per year.

The calculations utilized to reduce the Point Source Listings data to the waste heat values presented in this report are contained in Appendix B.

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* "OAQPS Guidelines: Aeros Manual Series. Volume 5. Aeros Manual of Codes," EPA-450/2-76-005 (April 1976).

APPENDIX B

HEAT CONTENT COMPUTATION OF WASTE HEAT DISCHARGES

Flue Gas Waste Heat

The heat content of the products of combustion (i.e., flue gas) was estimated using the following:

$$H_f = Jo\, C_{pm}\, (T - To) \qquad (1)$$

where

H_f = Heat content of the flue gas (Btu)

Jo = The volume of flue gas discharged (Ft^3)

T = Discharge temperature of flue gas (°F)

To = Ambient temperature (80°F)

$$C_{pm} = \Sigma_i X_i C_{pi} \qquad (2)$$

where

C_{pm} = Average specific heat for a multi-component gas ($Btu/F^3 \cdot {}^\circ F$)

X_i = Percent by volume of a component of the flue gas

C_{pm} = Average specific heat over the temperature range 80°F to 3000°F

Based on an estimation of the average volume fractions of the various flue gas components contained in the flue gases from the industries included in this study, a C_{pm} of 0.025 $Btu/F^3 \cdot {}^\circ F$ was utilized in these calculations. This figure is accurate to ± 12%.

Particulates

Much of the data on flue gases also contained discharge rates of the particulates contained in the flue gas waste heat discharges. It was therefore necessary to estimate the heat content of the particulates contained in the flue gas.

The specific heat (C_p) of particulates was estimated, to within ±15%, by the following relationships to the C_p of Coal:

$$C_p = 0.20 + 0.00088t + 0.0015v \qquad (3)$$

where C_p = Btu/lb of ash · °F

t = °F

v = wt.% of volatile matter (assumed to be 0.0 for flue gas particulates)

The average specific heat (C_{pm}) dependency upon temperature was determined using the following:

$$C_{pm} = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} C_p dt \qquad (4)$$

By integration of the above equation it was possible to plot the C_{pm} of the particulates over several differential temperature ranges. This data was then fit to the following power cume with a coefficient of determination of 0.995.

$$C_{pmp80} = 0.01386 \, (T)^{0.50628} \qquad (5)$$

where C_{pmp80} = Average specific heat for particulates discharged at T expressed as Btu/lb/°F

T = Discharge temperature of the flue gas (°F)

The heat content of the particulates in the flue gas was therefore calculated using the following equation.

$$H_p = J_p \, C_{pmp80} \, (T - To) \qquad (6)$$

where H_p = Heat content of flue gas particulates (Btu)

J_p = Quantity of particulates (lb)

C_{pmp80} = Average specific heat of particulates

T = Discharge temperature of the flue gas

To = Ambient temperature, assumed as 80°F

Therefore, the total waste heat discharge of a flue gas containing particulates was expressed as:

$$H_t = \left[Jo \, C_{pm} \, (T - To)\right] + \left[d_p \, C_{pmp80} \, (T - To)\right] \qquad (7)$$

where H_t = The total heat content of the flue gas between the discharge temperature and 80°F

GLOSSARY

Bdl: Barrels of Oil (equivalent to 42 Gallons of Oil)

BPD: Barrels per Day

Btu: British Thermal Unit, equal to 1,055 Joules

Btu available: Quantity of waste heat discharged at temperatures equal to or greater than 350°F.

contact cooling waters: Waters used for cooling purposes which come in direct contact with any product or by-product of the process.

differential temperature: Difference in temperature between the process stream and ambient conditions.

industrial diversification factor: Represents the number of 4-Digit SIC categories within its repsective 2-Digit SIC category.

IPP#: Implementation Planning Program Process Identification as defined in NEDS specific codes, OAQPS Guidelines, Aeros Manual Series, Volume V: AEROS Manual of Codes, EPA #450/2-76-005 (OAQPS No. 1.2-042).

NEDS: National Emissions Data System, OAQPS. U.S. EPA.

non-contact cooling waters: Waters used for cooling purposes which do not come into contact with the product or by-products and are discharged or recycled without degradation of the initial water quality other than elevation in temperature.

OAQPS: Office of Air Quality Planning Standards, U.S. Environmental Protection Agency, Research Triangel Park, North Carolina, 27711.

percent Btu available: Quantity of waste heat discharged at temperatures equal to or greater than 350°F expressed as a percentage of the total quantity of waste heat discharged at greater than or equal to 80°F.

percent waste heat: Quantity of waste heat discharged expressed as a percentage of the total purchased fuels and electricity.

process waters: Waters discharged as spent liquors, wet scrubbing liquors, contact cooling, etc., in which water quality is degraded by contact with the product or by-products or required treatment.